



Advanced High Temperature Polymer Matrix Composites for Gas Turbine Engines Program Expansion

David Hanley and John Carella
AlliedSignal Aerospace, Phoenix, Arizona

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1.0 INTRODUCTION

This document, submitted by AlliedSignal Engines (AE), a division of AlliedSignal Aerospace Company, presents the program final report for the Advanced High Temperature Polymer Matrix Composites for Gas Turbine Engines Program Expansion in compliance with data requirements in the statement of work, Contract # NAS-97003. This document includes:

1-Technical Summary:

- a) Component Design
- b) Manufacturing Process Selection
- c) Vendor selection
- d) Testing Validation

2-Program Conclusion and Perspective. Also, see the Appendix at the back of this report.

This report covers the program accomplishments from December 1, 1996, to August 24, 1998.

The Advanced High Temperature PMC's for Gas Turbine Engines Program Expansion was a one year long, five task technical effort aimed at designing, fabricating and testing a turbine engine component using NASA's high temperature resin system AMB-21. The fiber material chosen was graphite T650-35, 3K, 8HS with UC-309 sizing. The first four tasks included component design and manufacturing process selection, vendor selection, component fabrication and validation testing. The final task involved monthly financial and technical reports.

2.0 TECHNICAL SUMMARY

2.1 Task 1 - Component Design:

Objective

The objective was to redesign the 331-500 auxiliary power unit (APU) surge duct. The current production surge duct design is shown in Figure 1. The surge duct functions as a conduit for compressor discharge air and regulates potential surge conditions within the APU operating system. The 331-500 is the APU model that powers the electrical and hydraulic systems of the Boeing 777 aircraft during ground operation. In addition, Figure 2 shows the surge duct installed on the APU (see attachment #5 for color picture of engine).

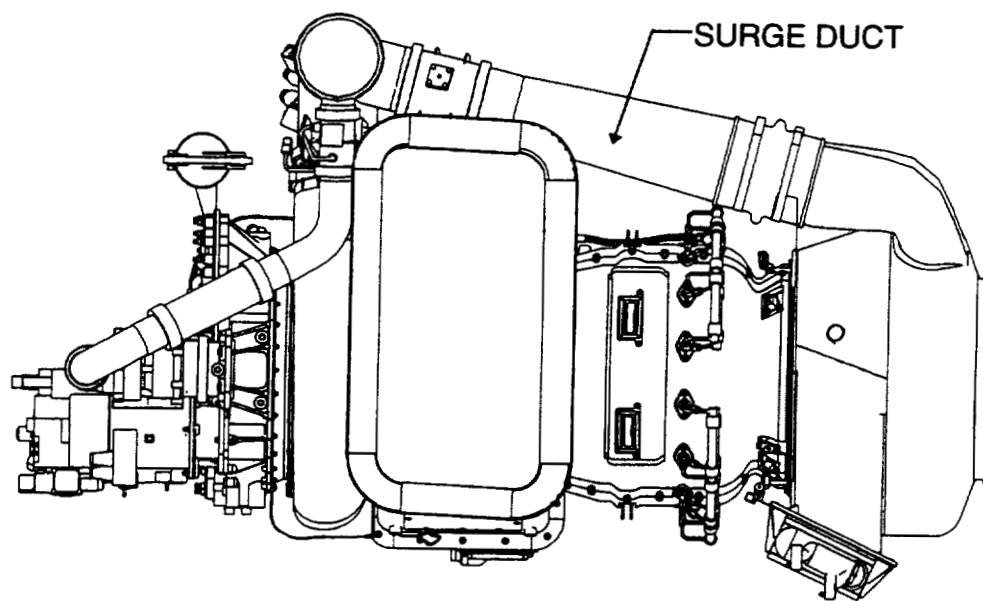


Figure 1

Design Task Description

This task consisted of a redesign of the current metal duct to a composite design. Some of the duct features, such as the V-band clamp/Marmon flange attachment to the composite duct, would have to be modified for composite fabrication. The design would make use of internal research test data assessing secondarily bonded attachments, variations of adhesive type, bond-line thickness, and relative positions of composite and metal adherends.

Problem Statement

The current design criteria are:

- Max internal pressure (Ultimate condition): 100 PSI.
- Max temperature: 500°F.
- Normal operating temperature is 400°F.

The current construction is:

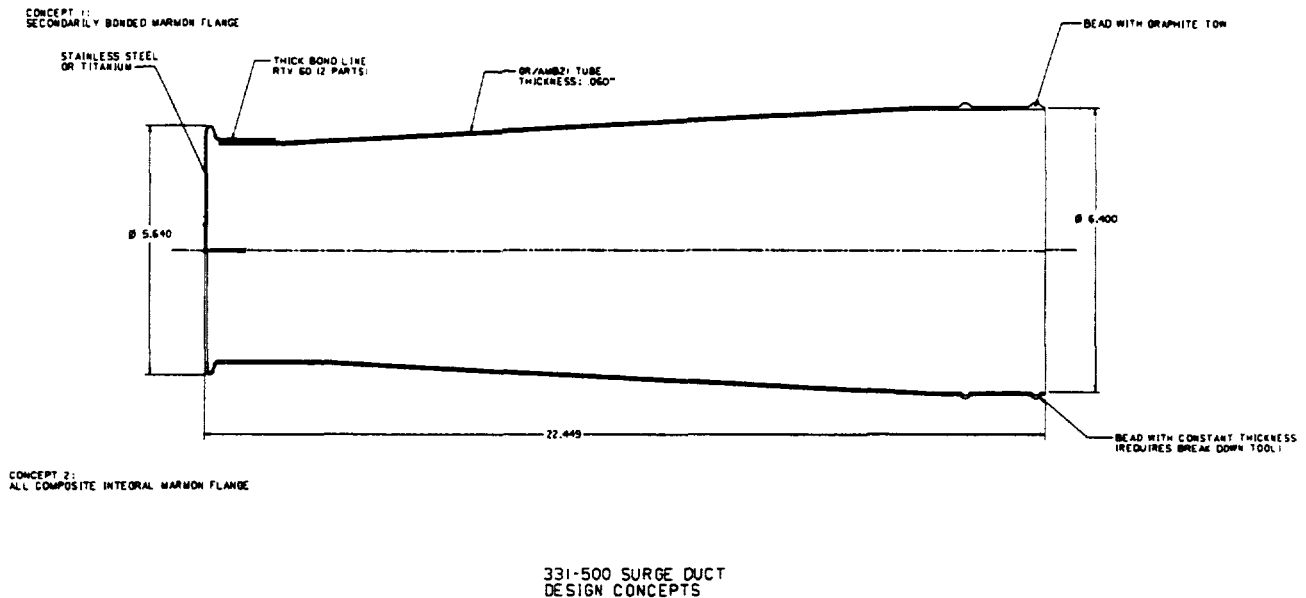
- Material currently used is Ti- 6-2-4-2.
- Rolled and welded sheet metal construction.

Design Features

The surge duct is constructed with a marmon flange at the forward end that serves as the attachment feature to the adjacent surge valve housing. The aft end has two beads that provide a locking feature to the clamp that attaches the surge duct to its mating rubber duct.

2.1.1 Surge Duct Design Concepts

Several design concept details of the duct (marmon flange and bead) are shown on the sketch below and described in the following paragraphs.



2.1.2 Options for V-Band Clamp/Marmon Flange Construction/Attachment

As described earlier, the surge duct is constructed with a marmon flange at one end that serves as the attachment feature to the mating surge valve housing. In order to select the most appropriate design for the surge duct, existing thermo-mechanical test data performed on a group of specimens manufactured with each specific bond type was utilized. These tests were done in support of AE internal production issues. Each specimen comprised of a 5" diameter aluminum tube bonded to a composite tube, with varying bond-line thickness and relative aluminum/composite positions. The testing consisted of thermal cycling half of the specimens from 0°F to 300°F, for ten cycles and then mechanically loading the specimens in compression to failure. The test results have allowed us to draw several conclusions and to select preferred design configurations:

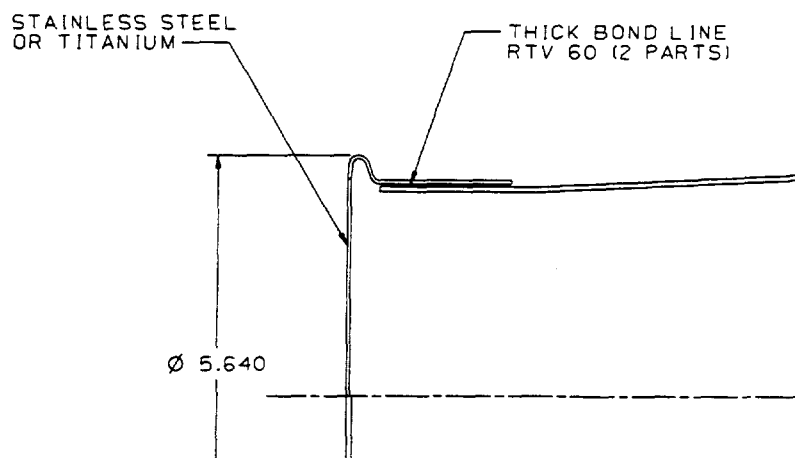
- High temperature RTV 106 (henceforth referred to as RTV) thick bond-line (approximately .030") is better under a tension load (up to 50% elongation is tolerable), when there is a coefficient of thermal expansion (CTE) mismatch between the composite tube and the metal flange. The CTE for metals such as titanium or stainless steel is greater than the CTE of graphite/AMB-21. Therefore, the metal flange should be positioned on the outside of the composite tube.
- High temperature polyimide adhesives should be used for applications under compressive load. A typical bond-line thickness is .005 to .010 inches. Therefore the metal flange should be positioned on the inside of the composite duct.

2.1.3 Preferred Design Options Based on Technical & Program Risk Assessment

Option 1:

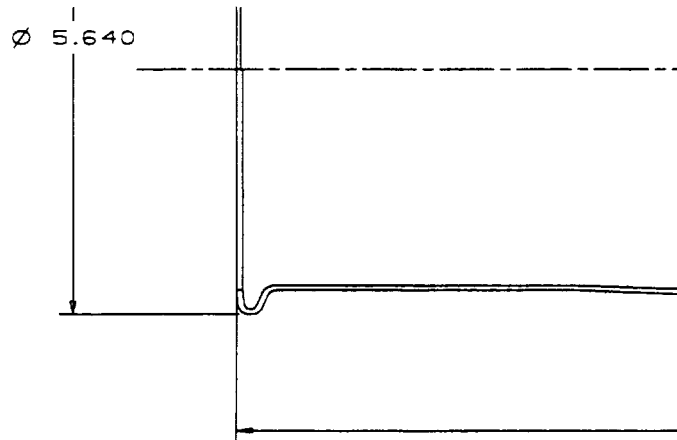
- Composite tube hand lay-up, filament wound or braided-RTM with a secondarily bonded metal flange.
- The flange may be bonded outside the composite duct with high temperature RTV adhesive (see sketch concept 1) or inside the composite duct with high temperature polyimide adhesive.
- Technical risk: Low. Hand lay-up methods have been demonstrated, but filament winding and RTM processing were removed from further consideration due to poor quality results of AMB-21 in process development. However, -60°F to +500°F cycling may be an issue for bond-line durability.
- Program risk: Low.

CONCEPT 1:
SECONDARILY BONDED MARMON FLANGE



Option 2:

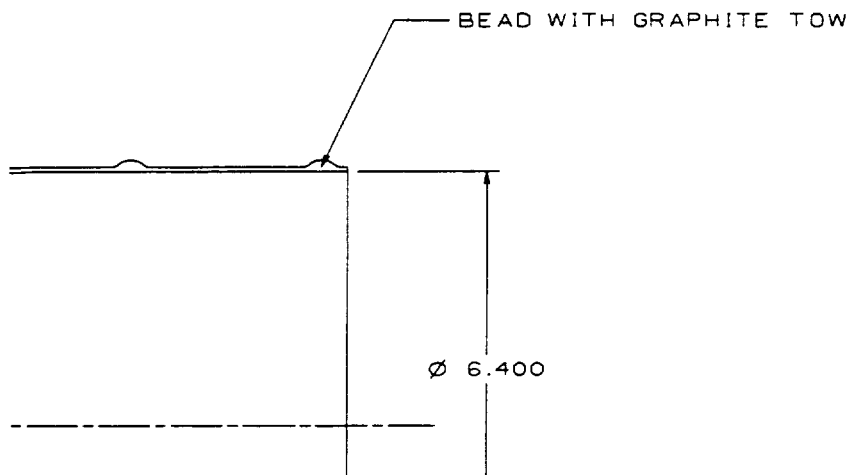
- Composite tube hand lay-up with integral Marmon flange (see sketch concept 2).
- Technical risk: Medium/high. Stress at flange may be an issue due to differential CTE with mating metal flange. Also, manufacturing a good quality flange with minimum darting (hand lay-up) may be difficult to achieve.
- Program risk: Medium/high

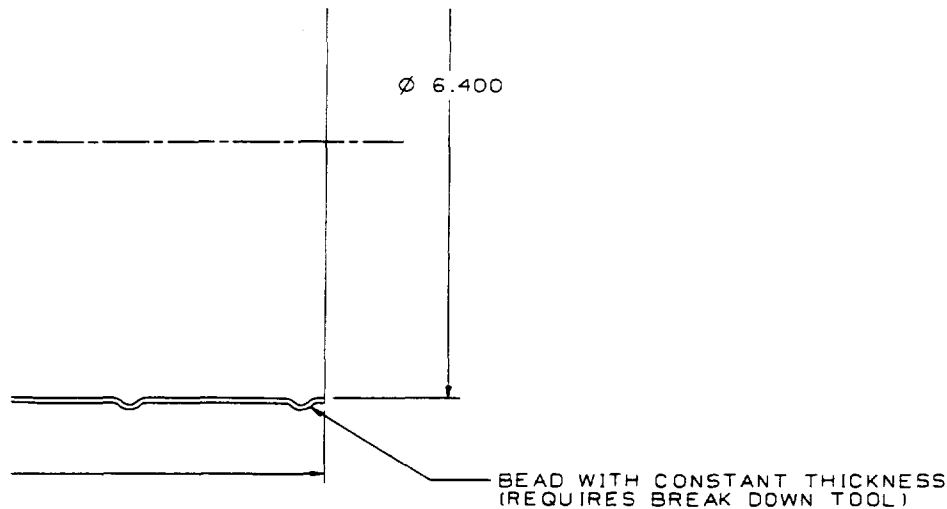


CONCEPT 2:
ALL COMPOSITE INTEGRAL MARMON FLANGE

2.1.4 Additional Features

The two sketches below illustrate two approaches for fabrication of the bead at the opposite end of the surge duct.





2.1.5 Processing Method Selection

The following processes were the three options being considered to fabricate the composite surge duct:

1. *Filament Winding*: This method of fabrication was initially the preferred approach due to the surface of revolution geometry of the surge duct. Also, filament winding would eliminate the time consuming de-bulking process used on hand lay-up parts as well as have cheaper raw material acquisition and storage costs. However, filament winding process development of AMB-21 under another program has resulted in significant technical issues. It was determined that these issues could not be solved within the scope of this program. It should be noted that many of the "technical issues" were the result of poor execution on the part of the vendor chosen for the process development.
2. *Hand Lay-Up*: This method of fabrication was then considered to be the primary approach due to its favorable risk/reward ratio in terms of being able to finish the program within budget.
3. *RTM with Braided Pre-form*: This process was still being evaluated and remains the most viable long-term method of fabrication due to its low material acquisition and storage costs, versatility and the minimal amount of trimming/machining required. However the RTM process would require a significant investment in tooling and process development that pushed it outside the scope of this program.

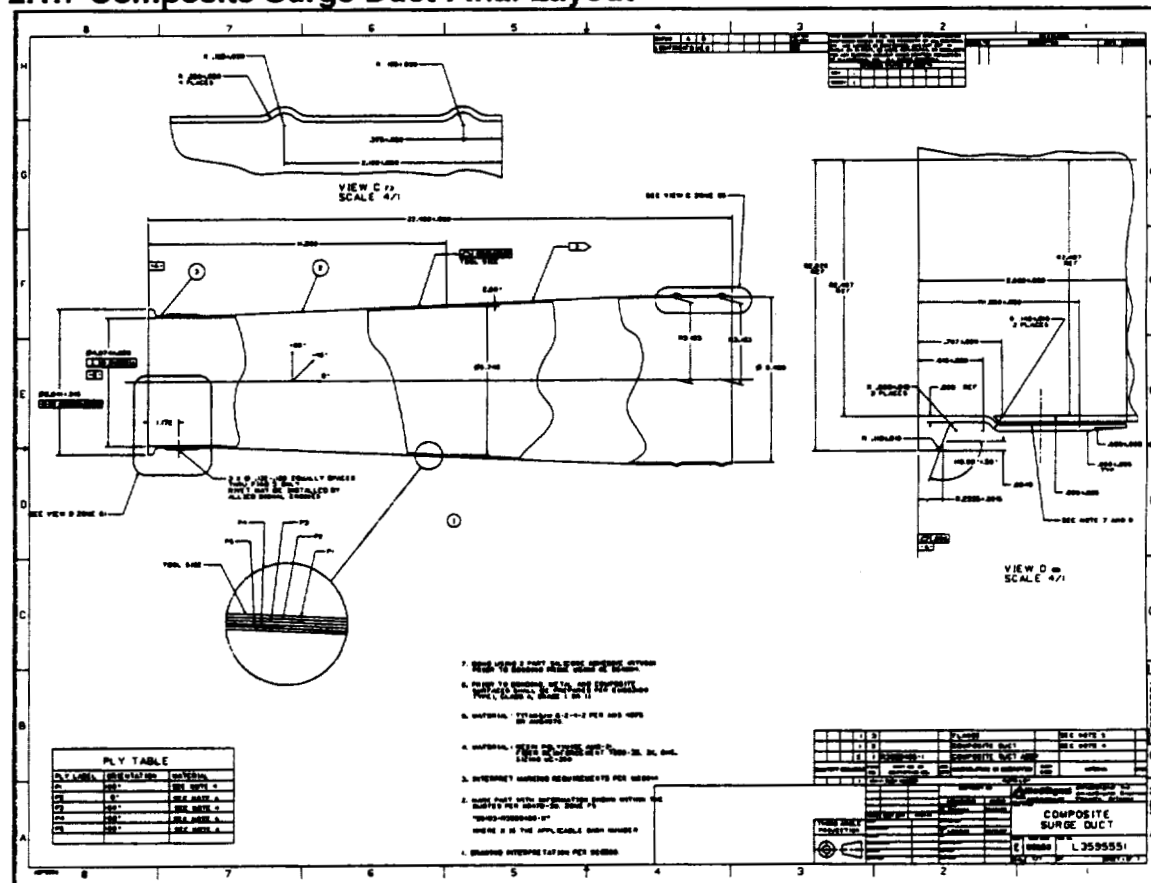
2.1.6 Final Design Selection

- Composite tube hand lay-up.
- Hand lay-up has been selected as the method of fabrication to minimize risk and because the filament winding and RTM processes do not offer enough chance of success at this stage of development.
- The marmon flange is machined out of titanium.
- The flange is bonded outside the composite tube with high temperature RTV adhesive.
- Lay-up stack: [0,90,60,-60,60]. The first ply is oriented in the hoop direction to carry the pressure load. The second ply is oriented at 90 degree to balance the first ply. The remaining three plies are oriented at $\pm 60^\circ$ degree to minimize the wrinkling effects that occurs after the loss of matrix mass after imidization.

Additionally, the $\pm 60^\circ$ plies will also carry part of the pressure load.

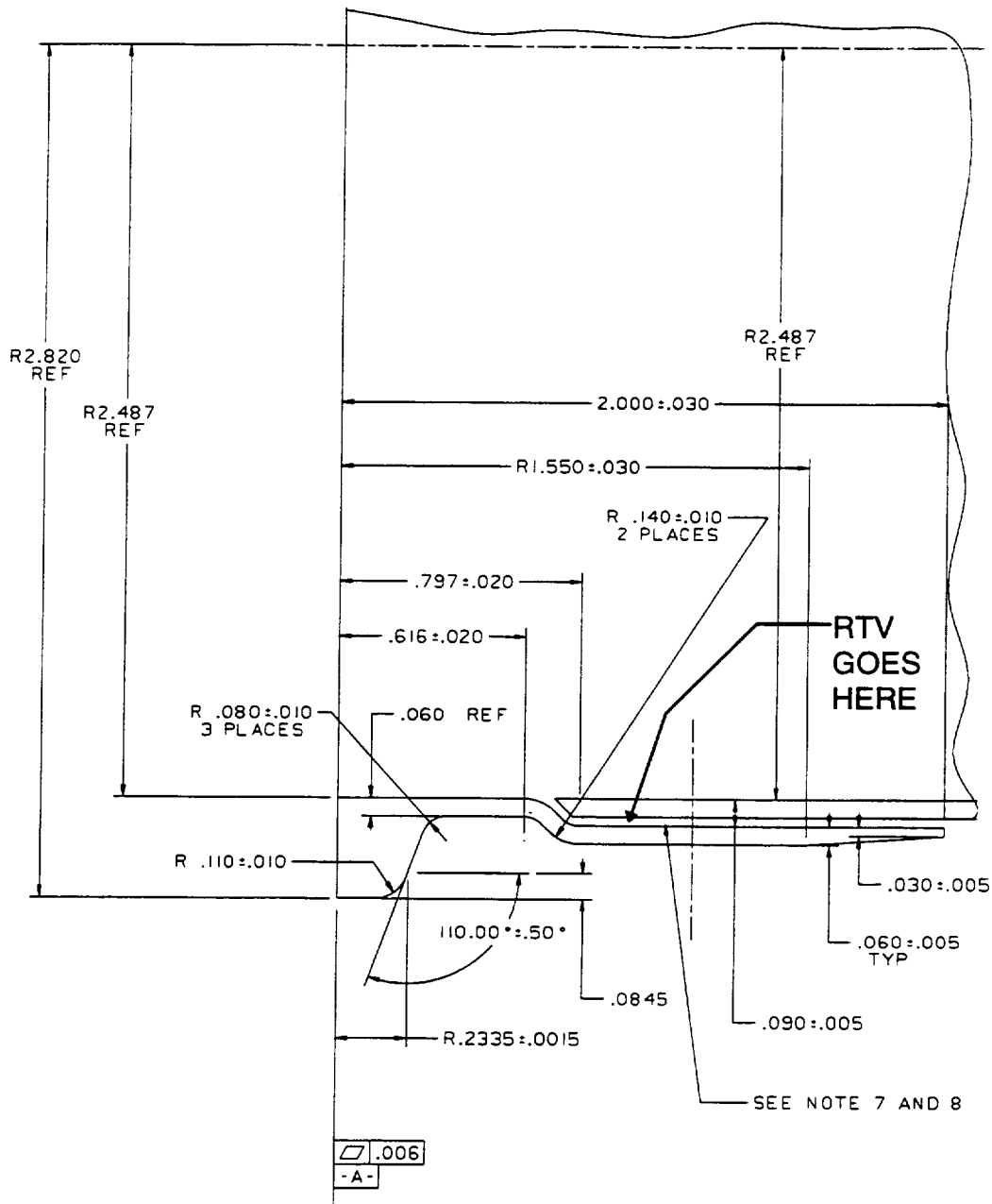
- Technical risk: Low. Processing method has been demonstrated, however the -60 to + 500°F cycling may be an issue on the bond-line.
- Program risk: Low.

2.1.7 Composite Surge Duct Final Layout



2.1.8 Composite Surge Duct Flange Detail

This figure shows the flange details and its interface with the composite duct.



2.1.9 Analysis

A) Static Analysis

A complete 3-D analysis was performed on the composite surge duct using the ANSYS analysis code.

Boundary conditions:

Fixed (3 translations and 3 rotations) at the marmon flange.

Fixed (1 translation in the radial direction).

Material assumptions:

$$E = 6.5 \times 10^6 \text{ lb/in}^2$$

$$\text{Nu} = .3$$

Geometric assumptions:

Thickness = .060" (5 plies of .012" each).

The table below provides some of the Stress/Strain levels at the Ultimate and Limit Load Conditions:

HOOP DIRECTION			
	Max Hoop Strain	Maximum Strain Allowed	Strain Margin
Ultimate Load 100 PSI Burst pressure = (300 % of maximum normal operating system pressure)	.000878 in/in	.007000 in/in (0.7%)	6.97 strain margin =(allowable strain / actual strain) - 1
Limit Load 50 PSI (2 times normal operating pressure)	.000439 in/in	.004000 in/in (0.4%)	8.11
AXIAL DIRECTION			
	Max Axial Strain Compressive & Tensile	Max Strain Allowed Compressive & Tensile	Strain Margin
Ultimate Load 100 PSI Burst pressure	Compressive: -.000466 in/in Tensile: +.000229 in/in	Compressive: .007000 in/in (0.7%) Tensile: .007000 in/in (0.7%)	Compressive: 14.02 Tensile: 29.57
Limit Load 50 PSI (2 times normal operating pressure)	Compressive: -.000233 in/in Tensile: +.000115 in/in	Compressive: .004000 in/in (0.4%) Tensile: .004000 in/in (0.4%)	Compressive: 16.17 Tensile: 33.93

B) Modal Analysis

Modal analysis was performed on the composite surge duct using the ANSYS code.

The first mode of the composite surge duct is 650 Hz which is greater than the current production titanium surge duct first mode (412 Hz). This confirms that the composite surge duct is a stiffer structure than the current metal configuration and should perform as well or better in the vibration environment of the APU.

C) Conclusion

The surge duct strain level, at both limit and ultimate conditions, are well below the maximum allowed. Therefore this structure has enough margin to account for any likely material degradation due to thermal exposure and due to initial fabrication defects such as voids or other laminate deficiencies.

2.2 Task 2 - Vendor Selection

A request for quotation was sent out to four potential suppliers. A detailed statement of work, including all technical and quality requirements, as well as the final detailed layout of the composite surge duct were sent as part of the quote package. The statement of work and the list of quoted suppliers are identified below:

2.2.1 Statement of Work

NRA - Phase II - REQUEST FOR QUOTE 331-500 APU COMPOSITE SURGE DUCT P/N R3559406

STATEMENT OF WORK

A) SUMMARY

AlliedSignal Engines (ASE) is soliciting proposals for the fabrication of the surge valve duct (P/N R3559406) for the 331-500 APU as described on drawing L3595551. The selected supplier will receive a contract to manufacture 3 ducts. These ducts will be used in development and for testing the capability of the material and the component.

This part is to be considered as development quality. The quality requirements that are to be met are as listed in the Detailed Proposal Request section of this document.

This program is specifically intended to demonstrate the capability of a new high-temperature resin system. This includes successfully processing the material to produce a part of sufficient quality and adequate strength.

AMB-21 (or derivative) is a newly formulated high-temperature polyimide resin system from NASA LeRC which is a non-MDA PMR-15 type material. It has previously been resin transfer molded (RTM) and layed-up using prepreg. This program will require some processing definition and thus technical/schedule risk and ASE is willing to accept this program on a best effort/time and materials basis.

B) SCHEDULE

The following dates identify the major program milestones. Attached is the overall program plan and schedule:

Response to Request for Detailed Quote	5-5-97
Supplier Selected by ASE	5-9-97
Delivery of First Duct by Supplier	7-30-97
Delivery of Remaining two Ducts by Supplier	9-01-97

C) DETAILED PROPOSAL REQUEST

Proposals will address the total program cost, the manufacturing approach, and the program schedule. The proposal may also include a baseline price for delivery of production components.

The final design may be modified to suit processing requirements and will be completed concurrently with the selected vendor. AE will provide process definition assistance and manufacturing support due to the nature of the resin system.

Program Cost - Delivery of Development Hardware

The total program cost shall include a breakdown of the following:

1. Tooling Cost.
2. Process Development including the estimated number of trial component sub-elements (tubes without end fittings).
3. Per Part Cost - materials and labor.

Manufacturing Process Definition

Included in the manufacturing process definition for processing of the high-temperature resin system selected for this program (AMB-21) shall be the following:

1. Process flow chart.
2. AMB-21 Process Definition Plan.
3. Identification and assessment of schedule and/or technical risk.
4. Approaches to reduce the technical or schedule risk.
5. Experience with programs of similar scope and new material systems.

Program Schedule

The program schedule shall include the following:

1. Overall program plan with milestones.
2. Provisions for monthly tracking of program progress (both financially and technically).

PROPOSAL ASSESSMENT

The criteria used to select the supplier for this program will be as follows:

1. Cost of program.
2. Technical/manufacturing risk.
3. Schedule.

PART DESCRIPTION

AE is responsible for the design and analysis of the composite surge duct (P/N R3559406).

Layout Drawing L3595551 of the duct provides definition of the duct shape and dimensions, as well as definition of the methods of fabricating the attachment features. One end of the duct has integrated beads necessary for the clamping surface. The opposite end, which mates to its adjoining part via a V-band (or marmon) clamp will consist of a titanium ring end-fitting that is secondarily bonded onto the composite tube structure by an elastomeric adhesive.

REQUIREMENTS OF THE FINISHED COMPONENT

- Postcured Tg >280C (RDS) or as measured on tag ends.
- Void Volume < 3%
- Resin content: 28 -35% by wt
- NDE C-scan of 100% of laminate surfaces. No indications greater than 1/4" in any dimension and no two indications spaced closer than 1.0". A maximum of 4 identifiable flaws allowed per duct.
- A-scan of the secondary bond interface 100% inspection with no detectable flaws allowed
- Surface appearance : The non-tooled side of the laminate shall be as uniform and consistent as possible given the processing characteristics of the AMB-21. The non-tooled surface shall not exhibit any large areas of resin ridges or dry spots. To the maximum extent, care shall be taken to reduce the

occurrence of (negative) wrinkles and puckers as a result of bagging and processing procedures.

2.2.2 Vendor Selection:

Four potential suppliers, Kaiser Compositenk, Composites Horizons, Inc., Wilson Composites Group, Inc., and R Cubed, were requested to quote the fabrication of three composite surge ducts, including tooling.

Wilson Composites Group, Inc. did not respond within the time allowed. After reviewing quote packages from the three remaining vendors: Kaiser Compositenk, Composites Horizons, Inc., and R Cubed, Composites Horizons, Inc. was selected.

The table below summarizes the vendor selection criteria used:

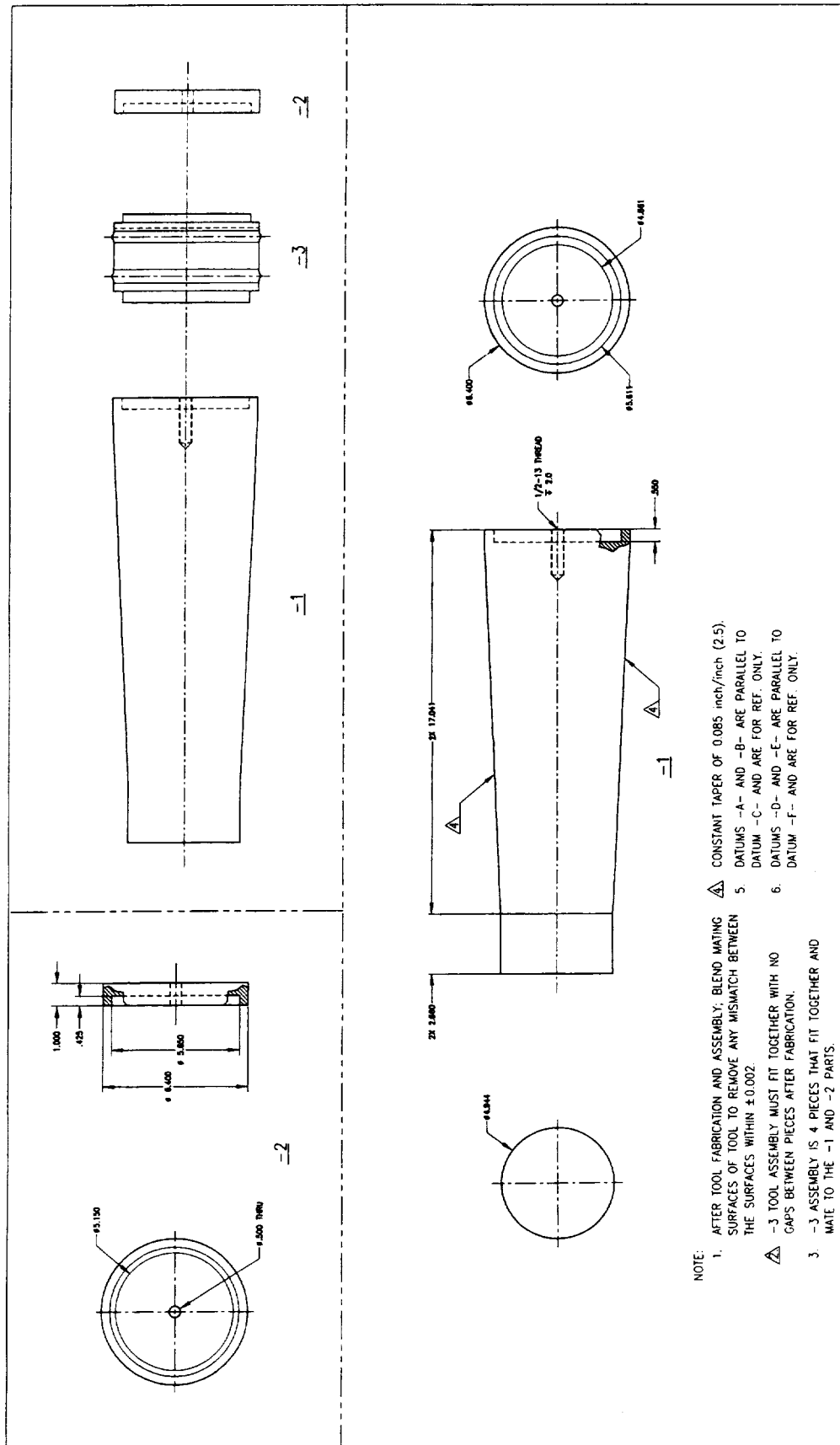
Criteria ^[13]	Composites Horizons	Kaiser Compositenk	R Cubed
High Temp. PMC Experience	High 5	Medium 3	Low 1
Cost	Medium 3	Medium/High 2	High 1
Overall Risk	Low 5	Medium 3	High 2
AVERAGE	4.3	2.6	1.3

1=negative impact to program 5=positive impact to program

2.3 Task 3 - Component Fabrication

2.3.1 Tooling

The lay-up tool was designed by Composite Horizon. The tool was originally made out of Aluminum but most of the processing was done with a steel tool which would be the material of choice for a production tool. This is due to the high temperatures seen by the tool during the cure cycle (600°F). It is comprised of two sections: one conical solid section and a break down mandrel section for the two beads at end of the duct. The lay-up tool drawings can be found in attachment 2. Figures 2 and 3 below, though hard to read, have been included for convenience.



NOTE:

1. AFTER TOOL FABRICATION AND ASSEMBLY, BLEND MATING SURFACES OF TOOL TO REMOVE ANY MISMATCH BETWEEN THE SURFACES WITHIN ± 0.002 .
2. Δ -3 TOOL ASSEMBLY MUST FIT TOGETHER WITH NO GAPS BETWEEN PIECES AFTER FABRICATION.
3. -3 ASSEMBLY IS 4 PIECES THAT FIT TOGETHER AND MATE TO THE -1 AND -2 PARTS.
4. Δ CONSTANT TAPER OF 0.085 inch/inch (2.5).
5. DATUMS -A- AND -B- ARE PARALLEL TO DATUM -C- AND ARE FOR REF. ONLY.
6. DATUMS -D- AND -E- ARE PARALLEL TO DATUM -F- AND ARE FOR REF. ONLY.

Figure 2

2.3.1 Processing

A total of ten ducts were processed at CHI. Of the ten, three ducts were of acceptable quality. Two of the ducts were used for testing and the third duct will be sent to NASA (the third duct was the tenth duct fabricated and had the best overall quality. Typical problems were excessive circumferential and some longitudinal wrinkling, resin flowing into the hollow portion of the tool during the curing process, difficulty curing the RTV that bonds the V-band clamp to the duct and indentations in the laminate caused by the release material.

Also, there was blistering that occurred in the laminate during post-cure, the out-time of the AMB-21 was exceeded, there was an oven controller failure and a bag was blown during the cure process.

All of the above problems can be considered to be part of the “growing pains” of learning to process a new material and all have been overcome with varying levels of difficulty.

CHI provided the following part-by-part summary of their AMB-21 materials and process development effort. A table summarizing CHI's efforts can be found at the conclusion of this part-by-part summary.

SURGE DUCT REPORT – WORK ORDER 5219

TOOL:

A 6 piece machined, breakdown tool made from 6061-T6 aluminum.

TEST NUMBER 1:

Lay-up, bagging and imidization procedure:

Room Temperature Debulk every ply except the first ply with vacuum bag and shrink wrap. Vacuum bag debulk first ply, no shrink tape.

Wrap part with FEP (a Non-Porous Teflon release film) and tape with 400 F tape.

Wrap part with one or two layers of shrink tape and pre-shrink the shrink tape with a heat gun.

Imidize part at $425\text{ F} \pm 10\text{ F}$ for 80 ± 10 minutes under 3-5 inches of Hg vacuum.

Remove bag and release materials and re-bag with one layer high temperature Teflon release material and one layer of Kapton shrink tape. Preshrink Kapton shrink tape and seal with Kapton tape.

Final Cure:

Apply full vacuum

Heat part to 400 F at 1-7 F/min.

Apply 200 ± 10 psi

Heat part to $600 \text{ F} \pm 10 \text{ F}$ at 1 - 3 F/min).

Hold at $600 \text{ F} \pm 10 \text{ F}$ for 165 ± 10 minutes under full vacuum and 200 ± 10 psi.

Cool to 400 F at 1-5 F/min.

Release vacuum and pressure

Cool to 150 F.

RESULTS:

Extensive wrinkling occurred after the initial imidization process along the circumference of the part. Approximately 30% of the outer surface of the part was covered with wrinkles. There were no longitudinal wrinkles observed. The circumferential wrinkles remained after the final cure. No reduction of wrinkles occurred during the final cure.

The "breakdown" section of the tool is hollow. The resin flowed extensively into the hollow part of the tool during the curing process. This caused difficulties during the part removal from the tool. No postcure was done due to the unacceptable quality of the part.

TEST NUMBER 2:

Lay-up, bagging and imidization procedure:

(Same as Test Number 1 except no shrink tape during imidization)

Room Temperature Debulk every ply except the first ply with vacuum bag and shrink-wrap. Vacuum bag debulk first ply, no shrink tape.

Wrap part with FEP (a Non-Porous Teflon release film) and tape with 400 F tape.

Wrap part with one layer of porous FEP and tape in place with 400 F tape.

Imidize part at $425 \text{ F} \pm 10 \text{ F}$ for 80 ± 10 minutes under 3-5 inches of Hg vacuum.

Remove bag and release materials and re-bag with one layer high temperature Teflon release material and one layer of Kapton shrink tape. Preshrink Kapton shrink tape and seal with Kapton tape.

Final Cure: Same as Test Number 1

RESULTS:

Minor wrinkling occurred after the initial imidization process along the circumference of the part. However, the size and amount of wrinkles were reduced compared to the first part. Approximately 10% of the part was covered with wrinkles. There were no longitudinal wrinkles observed. The amount of circumferential wrinkles increased after the final cure (approximately 20% of part outer surface).

The resin flowed extensively into the hollow part of the tool during the curing process. This caused difficulties during the part removal from the tool. No postcure was done due to the unacceptable quality of the part.

During the fabrication of this part, an observation was made that the diameter of the part after imidization was larger than the diameter of the tool at room temperature. Therefore, we concluded that the immediate application of vacuum during the second cure, before the part and tool was heated to 400 F, caused the part to wrinkle during cure.

TEST NUMBER 3:

(Same as Test Number 2 except the vacuum during the second/final cure is added when the part reaches 400 F)

Lay-up, bagging and imidization procedure:

Room Temperature Debulk every ply except the first ply with vacuum bag and shrink wrap. Vacuum bag debulk first ply, no shrink tape.

Wrap part with FEP (a Non-Porous Teflon release film) and tape with 400 F tape.

Wrap part with one layer of porous FEP and tape in place with 400 F tape.

Imidize part at $425\text{ F} \pm 10\text{ F}$ for 80 ± 10 minutes under 3-5 inches of Hg vacuum.

Remove bag and release materials and re-bag with one layer high temperature Teflon release material and one layer of Kapton shrink tape. Preshrink Kapton shrink tape and seal with Kapton tape.

Final Cure:

Heat part to 400 F at 1-7 F/min.

Apply full vacuum and 200 ± 10 psi

Heat part to $600\text{ F} \pm 10\text{ F}$ at 1 - 3 F/min

Hold at $600\text{ F} \pm 10\text{ F}$ for 165 ± 10 minutes under full vacuum and 200 ± 10 psi.

Cool to 400 F at 1-5 F/min.
Release vacuum and pressure
Cool to 150 F.
Postcure using PMR-15 postcure;
Ramp to 400 F \pm 10 F at a rate of 1-5 F/min.
Ramp to 600 F \pm 10 F at a rate of ½ -1 F/min and hold for 8 to 8.5 hours
(REF: Final Report for Allied Signal – AMB-21 Process Development)

RESULTS:

No wrinkling occurred after the initial imidization process. All the circumferential wrinkles were eliminated. However, after the final cure, two longitudinal wrinkles were located on opposite sides of the part. One of the wrinkles was approximately 0.060" high and 18 inches long. The other wrinkle is approximately 0.010" high and also 18 inches long.

A C-Scan of the part was also completed. It showed defects along the wrinkles and some areas of high attenuation (an extra 6 dB compared to the "clean" area of the duct) along the smaller wrinkle about 2 inches wide.

(Note: Lead tape on the outside of the duct was used as the basis for all C-Scans).

In order to control the resin flow into the hollow part of the tool during the cure process, one layer of fiberglass tape and one layer of Kapton tape approximately 0.25" wide were placed over the split lines of the tool. This almost eliminated resin flow into the tool and reduced the time for part removal by at least 50%.

The Tg testing was not completed due to the customer indicating that the wrinkles on the part were unacceptable.

TEST NUMBER 4:

Lay-up, bagging, and imidization procedure: (Same as Test Number 3 except 0.005" steel shims were placed around the part in order to eliminate wrinkles during the final cure)

Room Temperature Debulk every ply except the first ply with vacuum bag and shrink wrap. Vacuum bag debulk first ply, no shrink tape.
Wrap part with FEP (a Non-Porous Teflon release film) and tape with 400 F tape.
Wrap part with one layer of porous FEP and tape in place with 400 F tape.

Imidize part at $425\text{ F} \pm 10\text{ F}$ for 80 ± 10 minutes under 3-5 inches of Hg vacuum.

Place one layer of 0.005" shim along the length of the part. Use 6 pieces of shim around the circumference of the part. In addition, place one layer of shim material between the two "ridges" (large diameter end) and where the duct transitions to the flat section (small diameter end). All the pieces should overlap. Tape the shims in place with Kapton tape.

Wrap the part with one layer of Kapton shrink tape and tape in place with Kapton tape.

Final Cure and Postcure:

Heat part to 400 F at $1-7\text{ F/min}$.

Apply full vacuum and $200 \pm 10\text{ psi}$.

Heat part to $600\text{F} \pm 10\text{F}$ at $1-3\text{ F/minute}$.

Hold at $600\text{F} \pm 10\text{F}$ for 165 ± 5 minutes.

Cool to 100F at $1-10\text{F/minute}$ (Note: Release pressure and vent vacuum when part

reaches $400\text{F} \pm 10\text{F}$).

6) Postcure using PMR-15 postcure;

Ramp to $400\text{ F} \pm 10\text{ F}$ at a rate of $1-5\text{ F/min}$.

Ramp to $600\text{ F} \pm 10\text{ F}$ at a rate of $\frac{1}{2} - 1\text{ F/min}$ and hold for 8 to 8.5 hours (REF: Final Report for Allied Signal – AMB-21 Process Development)

RESULTS:

No part wrinkling occurred. However, the non-porous release material wrinkled during the cure and left some small indentations in the outer surface of the part. These indentations are estimated to be a maximum of 0.005" deep.

A C-Scan of the part was also completed. It showed good laminate quality. However, some indications due to the non-uniformity of the outer surface (indentations of the release material) of the part was also observed.

In order to control the resin flow into the hollow part of the tool during the cure process, one layer of fiberglass tape and one layer of Kapton tape approximately 0.25" wide were placed over the split lines of the tool.

The titanium fitting was bonded to the duct per the instructions listed in the next paragraph. The adhesive between the titanium and the duct did not cure completely overnight (after 12 hours). The assembly was then put in an oven at 180 F for 2 hours. The adhesive did not cure even after the elevated temperature application. Therefore, the titanium ring was removed from the assembly. During removal from the assembly, the duct

was damaged due to the force that was required to remove the ring. The damage was at the ridges at the large end of the duct. These were used to hold the duct during the removal process. This caused extensive delaminations and an unacceptable condition to the duct.

TITANIUM BONDING PROCEDURE:

The small end of the duct was trimmed to the drawing. The bond area was sanded with 180 grit sandpaper until all the shine was removed without sanding into the fibers. The GE SS-4004 primer was applied to the bond area and let air dry a minimum of 30 minutes. The titanium ring bond area was sanded with 180 grit sandpaper until all the shine was removed. The adjacent sections to the bond areas of the duct and the titanium ring were masked with masking tape and Teflon tape to protect the duct and titanium ring and to facilitate clean-up after the bond process. The GE SS-4004 primer was applied to the bond area and let air dry a minimum of 30 minutes.

The lay-up tool was used to align the titanium ring to the duct. The tool was shimmed at the titanium ring interface with 0.010" thick Teflon tape. The RTV60 silicone adhesive was applied to the duct bond surface and the titanium bond surface. The adhesive was allowed to cure overnight.

TEST NUMBER 5:

(Same lay-up, cure and bagging procedure as Test Number 4 except the lay-up tool was not used for bonding the titanium ring and no tape was used for masking the adjacent areas of the duct and titanium fitting).

RESULTS:

No part wrinkling occurred. However, the non-porous release material wrinkled during the cure and left some small indentations in the outer surface of the part. These indentations are estimated to be a maximum of 0.005" deep.

A C-Scan of the part was also completed. It showed good laminate quality. However, some indications due to the non-uniformity of the outer surface (indentations of the release material) of the part was also observed.

In order to control the resin flow into the hollow part of the tool during the cure process, one layer of fiberglass tape and one layer of Kapton tape approximately 0.25" wide were placed over the split lines of the tool.

Tg Testing: (Requirement >280 C)

(Note: The time between the end of the cure and the beginning of the postcure of the duct was approximately one week. Also, the time between postcure and the testing of the specimens was also approximately one week).

One set of specimens were tested, from the large diameter end and one set from the small diameter end. These specimens were tested per GE specification E50TF536-S1.

Large diameter: Average - 255 C Small Diameter: Average – 245 C

A third set of specimens were tested because the original specimens were not dried prior to testing. The average Tg of these specimens is 259 C.

The void content is 3.20 % and the Resin Content is 28.27%. The requirements for the void content and resin content are <3% and 28-35% respectively.

The bond between the duct and the titanium ring was successful. The adhesive was allowed to cure overnight. A-Scan of the bond area showed no un-bonds or other discrepancies.

This was Serial Number 1 of the deliverable parts.

TEST NUMBER 6: (Same as number 5 except a different postcure was used that was supplied by Jim Sutter of NASA)

Post Cure:

(The Post Cure was performed within 24 hours after the completion of the initial cure and the part was freestanding during the post cure process.)

Raise Temperature to 450F \pm 10F in 70 minutes and hold for a minimum of 120 minutes.

Raise Temperature to 490F \pm 10F in 30 minutes and hold for a minimum of 120 minutes.

Raise Temperature to 550F \pm 10F in 30 minutes and hold for a minimum of 120 minutes.

Raise Temperature to 600F \pm 10F in 60 minutes and hold for a minimum of 360 minutes.

Raise Temperature to 625F \pm 10F in 45 minutes and hold for a minimum of 720 minutes.

Lower Temperature to 150F \pm 10F in a minimum of 120 minutes

RESULTS:

(Same as Test Number 5 except for the physical test results):

Tg Testing:

(Note: Postcure was started within 24 hours from the end of the final cure and the test specimens were tested within one week after postcure)

One set of specimens were tested These specimens were tested per GE specification E50TF536-S1.

Tg Average - 285 C

A-Scan of the bond area showed no un-bonds or other discrepancies.

The void content is 1.39 % and the Resin Content is 27.5%.

This was Serial Number 2 of the deliverable parts.

TEST NUMBER 7:

(Same lay-up and cure process as number 6)

RESULTS:

No part wrinkling occurred. However, the non-porous release material wrinkled during the cure and left some small indentations in the outer surface of the part. These indentations are estimated to be a maximum of 0.005" deep. In addition, after postcure, two blisters were formed on the inner moldline of the part. One blister is approximately 1.25" X 6" and is located adjacent to the ridges and the other is approximately 3" X 1.25" and is located about 1 inch from the small diameter end.

A C-Scan of the part was also completed. It showed good laminate quality except for the blistered areas.

The formation of the blisters was assumed to be caused by the excessive out-time of the material. The out-time of the material before cure was 464 hours. The part was under full vacuum for 360 hours of the 464 hours.

TEST NUMBER 8:

(Same lay-up, bagging and cure process as number 6)

RESULTS:

No part wrinkling occurred. However, the non-porous release material wrinkled during the cure and left some small indentations in the outer surface of the part. The indentations are deeper and more extensive than previous parts.

Furthermore, during postcure, the part was exposed to 650 F due to failure of the oven controller. This caused delaminations in the part and therefore, was unacceptable.

TEST NUMBER 9:

(Same lay-up, bagging and cure process as number 6)

RESULTS:

The bag blew during the cure process at the beginning of the heat-up to the 600 F hold. The part was removed and re-bagged. Partial vacuum (3-6 inches of Hg) was applied at the beginning of the cure. This caused excessive longitudinal wrinkles in the part and was unacceptable.

TEST NUMBER 10:

(After further discussions with Allied Signal and within our Engineering department, CHI decided to use a new bagging procedure for the imidization and final cure process. Porous Armalon (TX1040) was used during the imidization and final cure to eliminate the surface indentations of the Non-Porous Teflon release. Also, the duct was allowed to free-stand in an oven during imidization without partial vacuum. In addition, a 190 F drying step was added to the postcure to reduce the possibility of blistering of the part. Finally, Teflon tape was used to mask the duct and titanium fitting during the bond process).

Lay-up, bagging, and imidization procedure:

Room Temperature Debulk every ply except the first ply with vacuum bag and shrink wrap. Vacuum bag debulk first ply, no shrink tape.

Spiral wrap part with porous Armalon (TX1040) as tight as possible

Wrap part with Non-Porous FEP (minimum of 1 inch overlap at the seam) and seal the ends with 400 F tape. Also, seal the seam $\frac{1}{2}$ the length of the part. Tape the other half of the FEP seam leaving a minimum of 1 inch gaps between the tape.

Imidize part at $425\text{ F} \pm 10\text{ F}$ for 100 ± 10 minutes freestanding in an oven. The part was placed in the oven on end.

The part was removed from oven and re-bagged as follows:

Cut 1.5 – 2 inch wide strips of porous Armalon (TX1040).

Locate the strips onto the part and tape tightly in place with Kapton tape. Overlap the seams a minimum of 0.5 inch. Place one layer of 0.005" shim along the length of the part. Tape in place using Kapton tape. Use 5-7 pieces of shim around the circumference of the part. All the pieces should overlap a minimum of 0.25 inch. The edges of the shims were sanded with fine Scotch Brite Pads to smooth the edges and reduce the mark-off. No shims were placed between the ridges. The shims were placed up to the edge of the ridge. Wrap the part with one layer of 1 inch Kapton shrink tape and tape in place with Kapton tape.

Cure:

- 1) Apply full vacuum and check for leaks.
- 2) Vent part to atmosphere.
- 3) Raise Temperature to $420\text{F} \pm 10\text{F}$ at 1-7 F/minute.

Apply full vacuum.

Apply 200 ± 10 PSI pressure.

Heat part to $600\text{F} \pm 10\text{F}$ at 1-3F/minute.

Hold at $600\text{F} \pm 10\text{F}$ for 165 ± 5 minutes.

Cool to 100 F at 1-10 F/minute (Note: Release pressure and vent vacuum when part reaches $400\text{F} \pm 10\text{F}$)

Post Cure:

(The Post Cure was performed within 24 hours after the completion of the initial cure and the part was freestanding during the post cure process.)

Raise Temperature to $190\text{F} \pm 10\text{F}$ in 20 minutes and hold for a minimum of 120 minutes.

Raise Temperature to $450\text{F} \pm 10\text{F}$ in 70 minutes and hold for a minimum of 120 minutes.

3) Raise Temperature to $490\text{F} \pm 10\text{F}$ in 30 minutes and hold for a minimum of 120 minutes.

4) Raise Temperature to $550\text{F} \pm 10\text{F}$ in 30 minutes and hold for a minimum of 120 minutes.

Raise Temperature to $600\text{F} \pm 10\text{F}$ in 60 minutes and hold for a minimum of 360 minutes.

Raise Temperature to $625\text{F} \pm 10\text{F}$ in 45 minutes and hold for a minimum of 720 minutes.

Lower Temperature to $150\text{F} \pm 10\text{F}$ in a minimum of 120 minutes

RESULTS:

The surface of the part did not have any of the surface indentations of the previous parts. The surface was generally smooth and consistent. There

was some small surface “mounds” in between the far ridge and the end of the shims. The wrinkles were a maximum of 0.5 inches long and approximately 0.010” high. The outer surface of the part also contained 0.003” lines caused by the mark-off of the shims onto the part.

The C-Scan showed a large amount of indications throughout the part which was worse than the previous test results. This was caused by the excessive out-time of the material. The material was at room temperature for 528 hours before the material was cured.

A-Scan of the bond area showed no un-bonds or other discrepancies.

Tg Testing:

(Note: Postcure was started within 24 hours from the end of the final cure and the test specimens were tested within one week after postcure)

One set of specimens were tested. These specimens were tested per GE specification E50TF536-S1.

Tg Average - 283 C

The void content is 1.73 % and the Resin Content is 29.94%. The discrepancy between the C-Scan data and physical data is due to where the samples for the physical tests were taken. The ends of the part had good consolidation and is verified in the C-Scan and observation of the ends of the part after trim. The majority of the part that showed discrepancies did not have samples removed for observation or physical testing.

2.3.3 Laminate quality Results

The table below describes the laminate quality result for the three ducts delivered by CHI:

SUMMARY OF AMB-21 MATERIAL SPECIMEN TESTING				
TEST NUM	SERIAL NUM	POSTCURED T _G	VOID VOLUME	RESIN CONTENT
		GOAL		
		>280 C (536F)	<3%	28-35 % by wt
1		ND	ND	ND
2		ND	ND	ND
3		ND	ND	ND
4		ND	ND	ND
5	001	259	3.20	28.27
6	002	285	1.39	27.50
7		ND	ND	ND
8		ND	ND	ND
9		ND	ND	ND
10	003	283	1.73	29.94

Note: ND = no data available

2.3.3 NDE Results

The attached materials show the composite surge duct's C-Scan results as well as other data supplied by CHI.

2.4 Task 4 - Testing

2.4.1 Instrumentation

Instrumentation consisted of 6 strain gages and 4 thermocouples. The detailed layout of the instrumentation is shown in Figure 5.

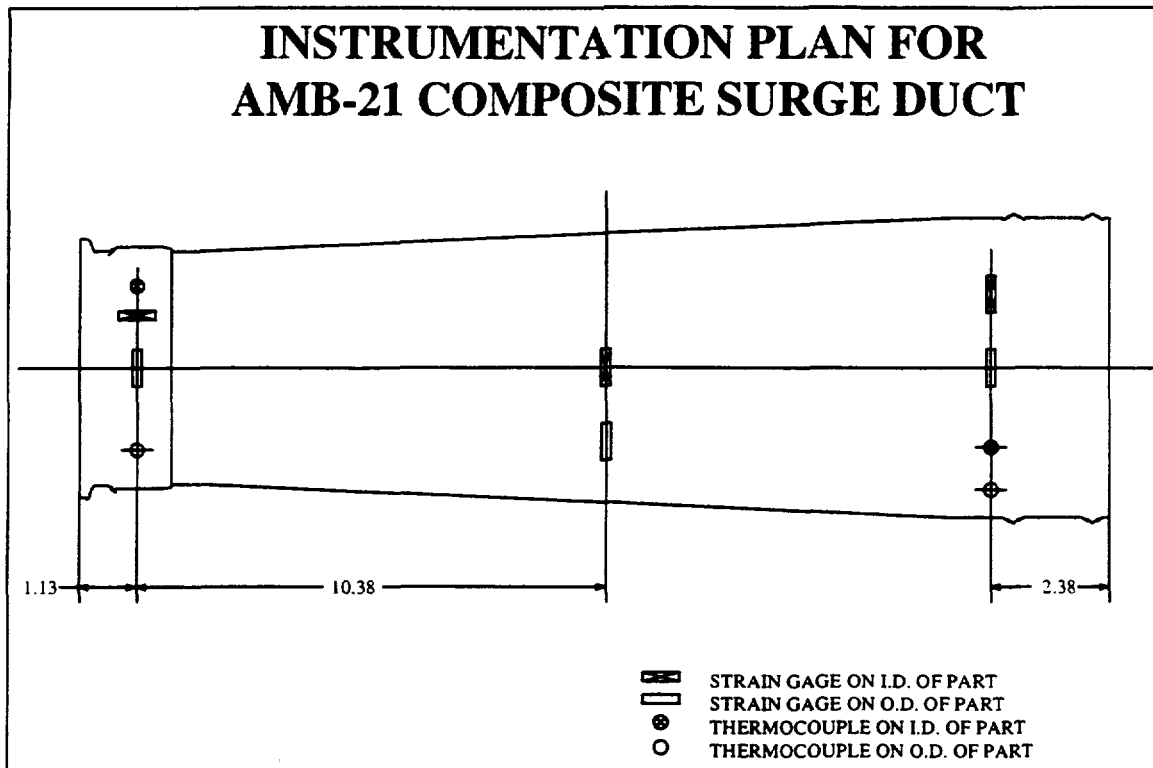


Figure 5

2.4.2 Testing Plan

NRA II 331-500 Composite Surge Duct Test Plan

I) Test Goal(s)

To validate Composite Surge Duct Material System and Design by simulating the mechanical (pressure) and environmental (temperature) engine conditions.

NOTE: Two tests were run on the surge duct. The first test was run at $T=430$ to 450 °F air temperature because the duct use was not processed to the correct T_G . After a "good" Duct was made, it was used on the second test which was run at the design air temperature ($T=490$ to 510 °F). Also, the first test ran for 61,500 cycles in an attempt to make the part fail while the second Duct ran for the design life of only 15,000 cycles.

II) Test Conditions

First Test

Test set-up will include:

- Compressed air (50 to 60 PSI) and heat source (T=430 to 450°F).
- Flow rate: 250 lbs/min.
- Surge valve controlled with the same logic program as on the engine.
- Composite Duct.
- Plenum (1 ft³).

III) Instrumentation

- Pressure (static and/or dynamic): located before and after the composite duct.
- Temperature (Tc's): located before and after the composite duct.
- Strain gages: located on the composite duct in longitudinal and hoop directions.

IV) Hardware Needed

- Surge Valve with Controller.
- Plenum.
- Rubber Duct with clamps.

V) Plan

Initial testing :

- 1) Apply 1000 cycles.
- 2) Visual inspection and leak check at bond joint.
- 3) If part shows no apparent defects, apply 1000 additional cycles.
- 4) Repeat step 2.
- 5) If part shows no apparent defects, apply 2500 additional cycles.
- 6) Repeat step 2.
- 7) If part shows no apparent defects, apply 5000 additional cycles.

Additional cycle testing will be evaluated as the testing progresses.

Second Test

Same as first test except as follows:

- The supply air temperature range will now be 490-510°F instead of the previous 430-450°F.

- The test will run for correct design life of 15,000 cycles instead of 61,500 cycles.

2.4.3 Test results

After 61,500 cycles the first test of the composite duct did not show any sign of degradation. The bond-line at the duct/flange interface also showed no sign of degradation. Similar results were achieved for the second test.

2.5 Conclusion and Perspectives

The Advanced High Temperature PMC's for Gas Turbine Engines Program Expansion technical effort has come to a successful conclusion. AlliedSignal has demonstrated that an AMB-21 Composite surge duct can be produced that meets all of the quality control and structural requirements of the titanium part that is currently being used in production on the 331-500 APU. With relatively minor "tweaking" of the fabrication process, AMB-21 can be a viable candidate material to fill the temperature capability gap between BMI and PMR-15 for future production hardware.

Finished part cost, however, remains the final hurdle to overcome before an AMB-21 part such as the surge duct can achieve production bill-of-material status. This is mainly due to the fact that there is virtually no AMB-21 currently being used in sufficient quantity to get the economies of scale necessary for its price to drop.

The next logical step to be taken on this program would be geared toward cost reduction. This can be achieved primarily by replacing the titanium machined forward flange with an off-the-shelf formed stainless steel sheet metal flange similar to the ones currently used in production at AlliedSignal (ref: Concept I shown in Section 2.1.1). This will help make the surge duct a more viable candidate for future derivatives of the 331-500 APU.

APPENDIX A

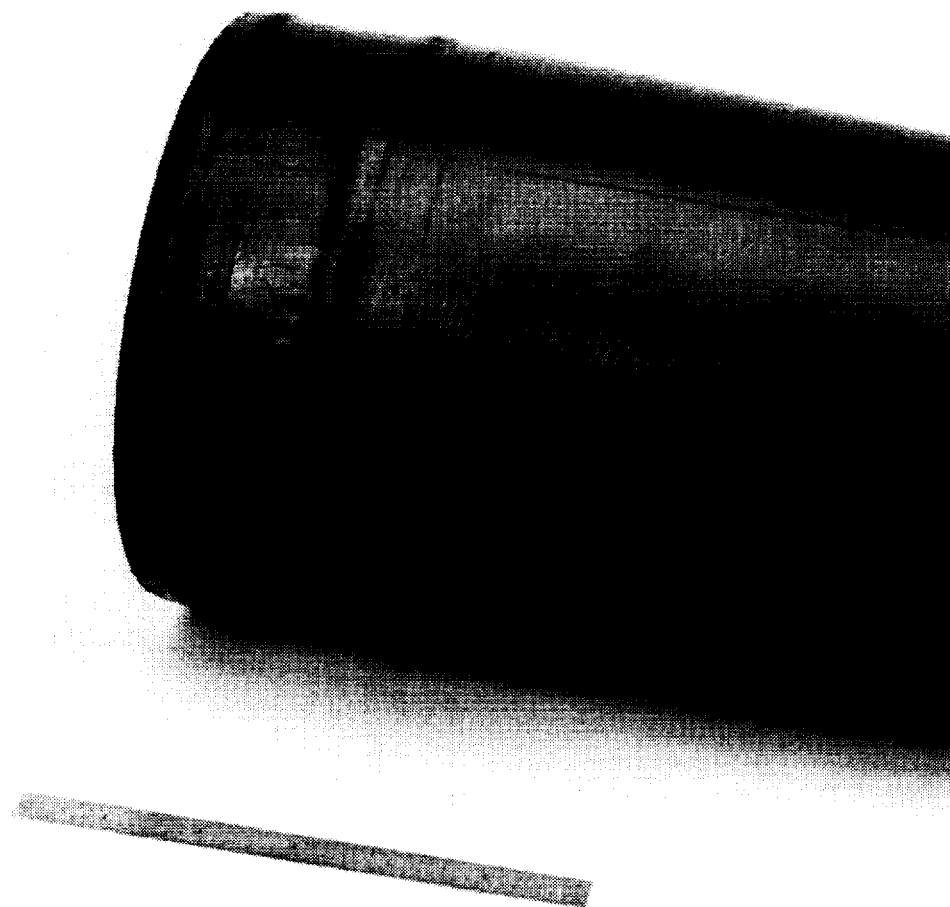


Figure A1a.

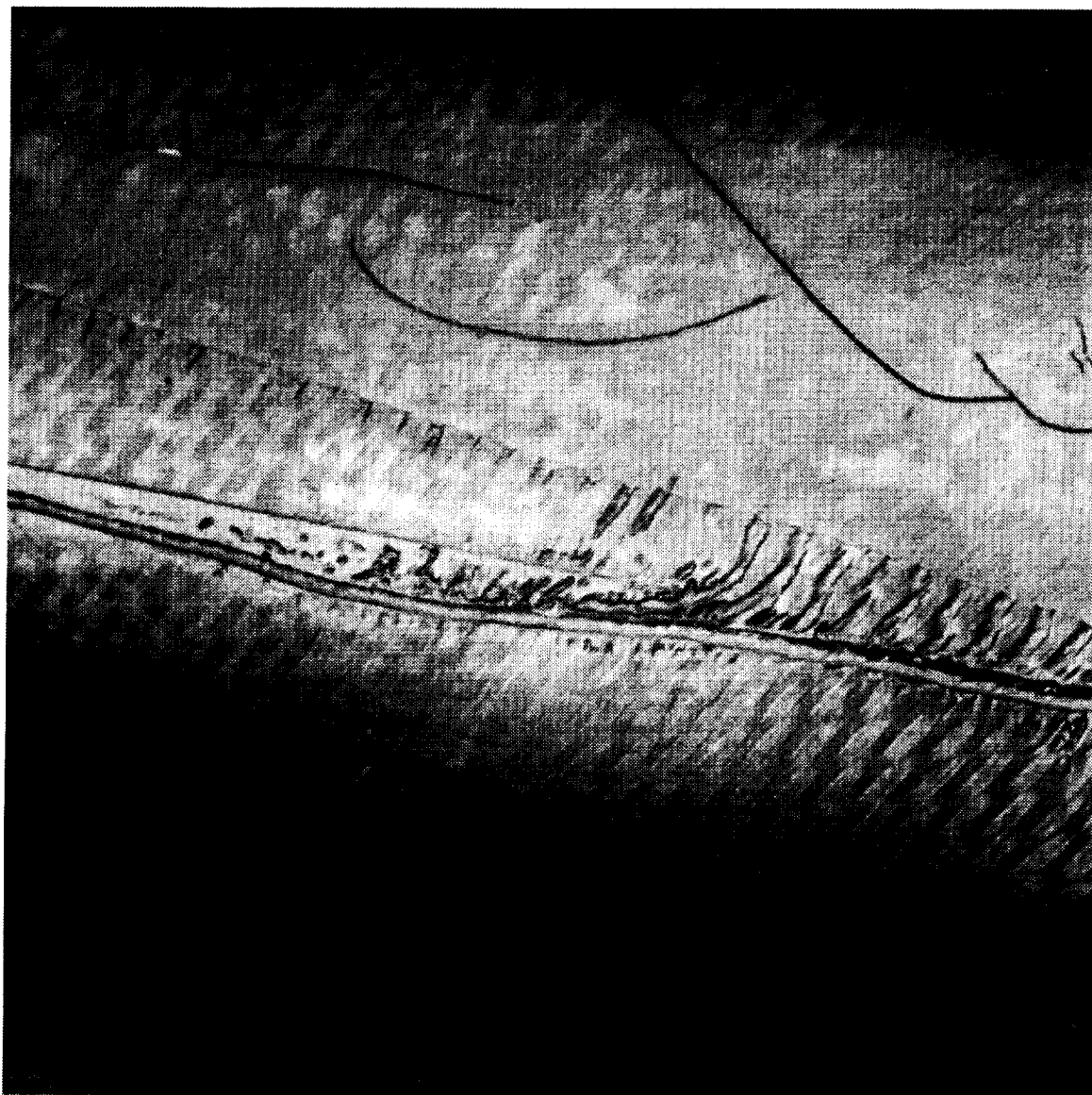


Figure A1b.—Wrinkling from autoclave processing of AMB-21 surge duct.

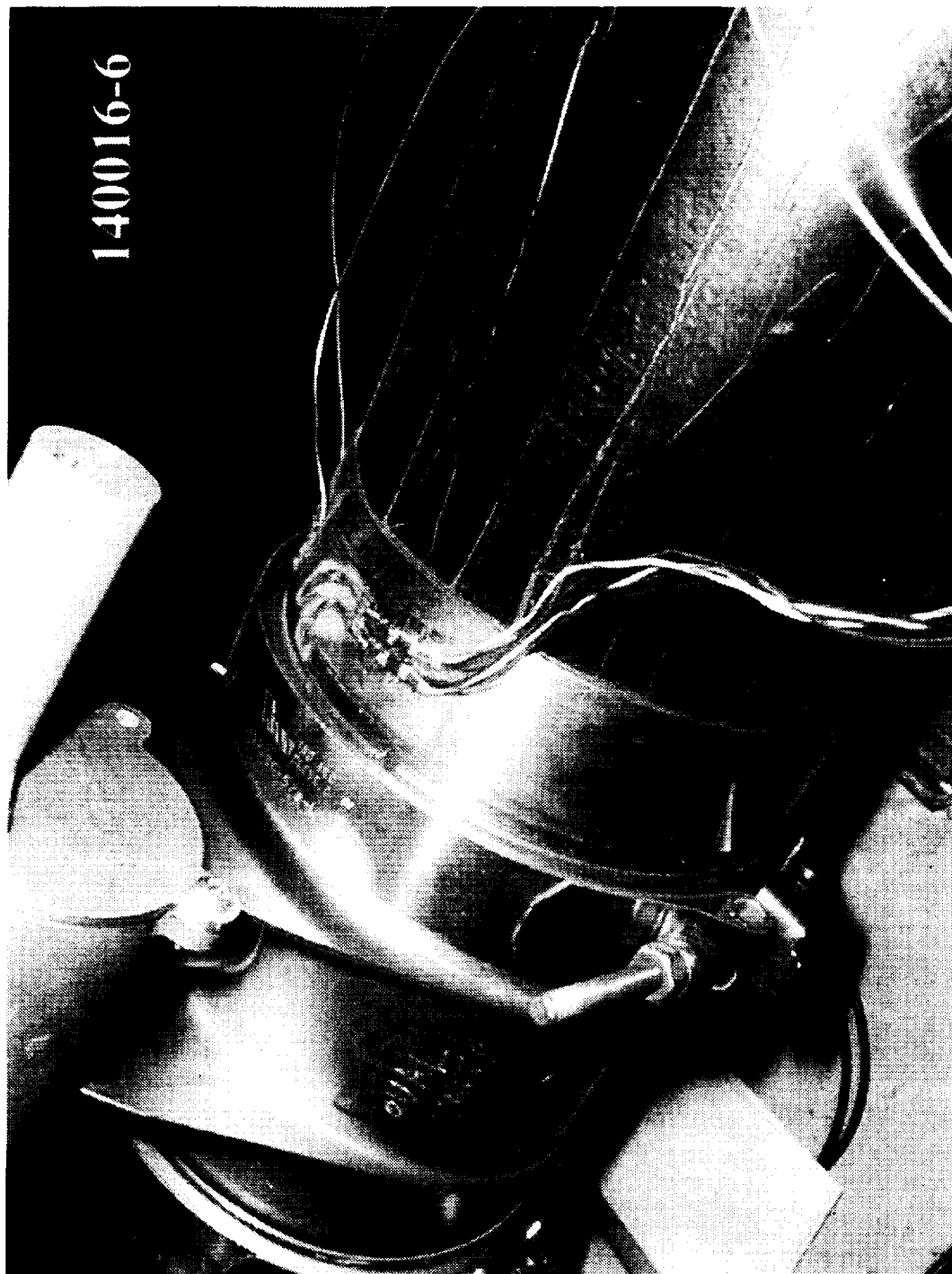


Figure A1c.—Marman flange on AMB-21 surge duct.

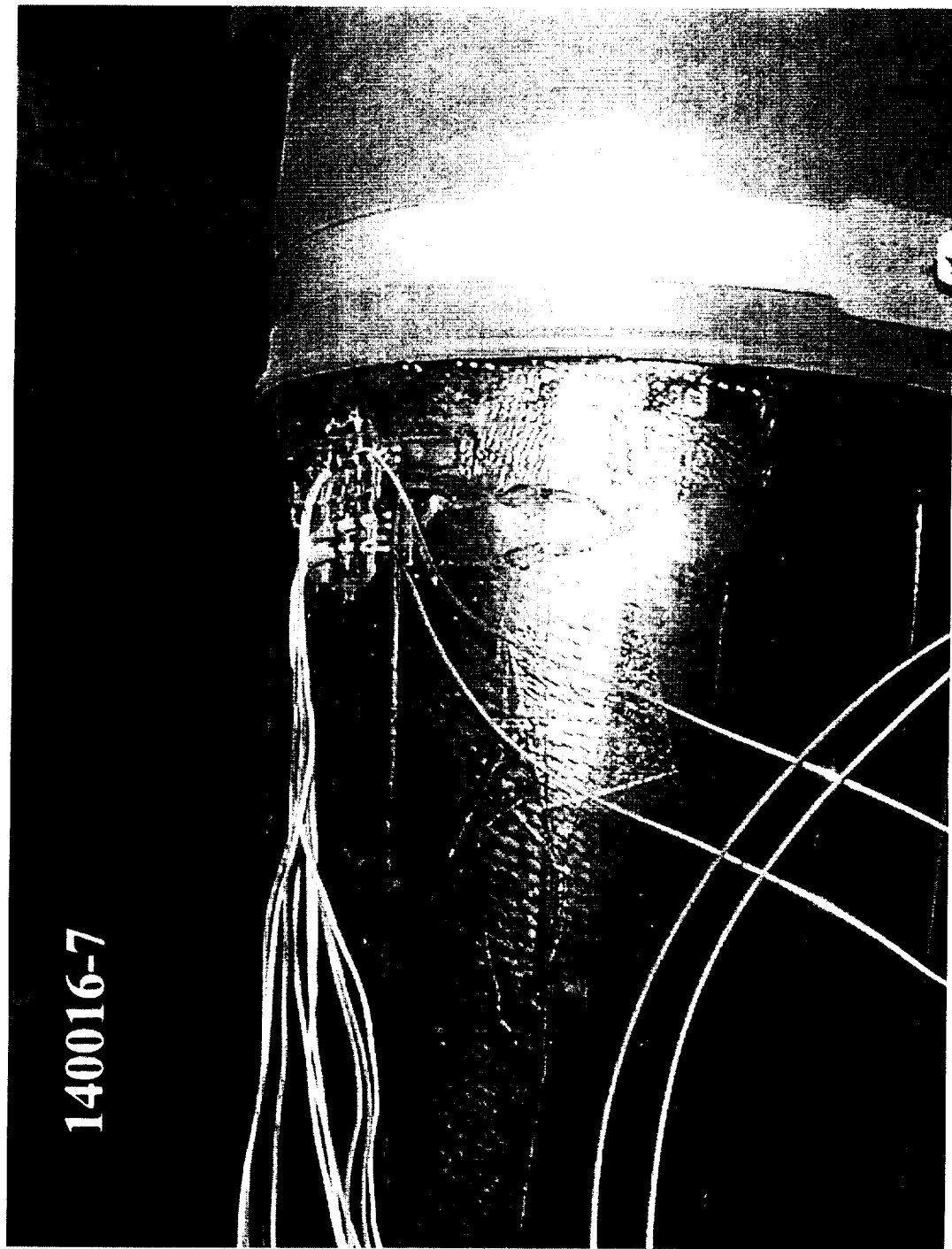


Figure A1d.—Straining gauge on V-band end of AMB-21 surge duct.

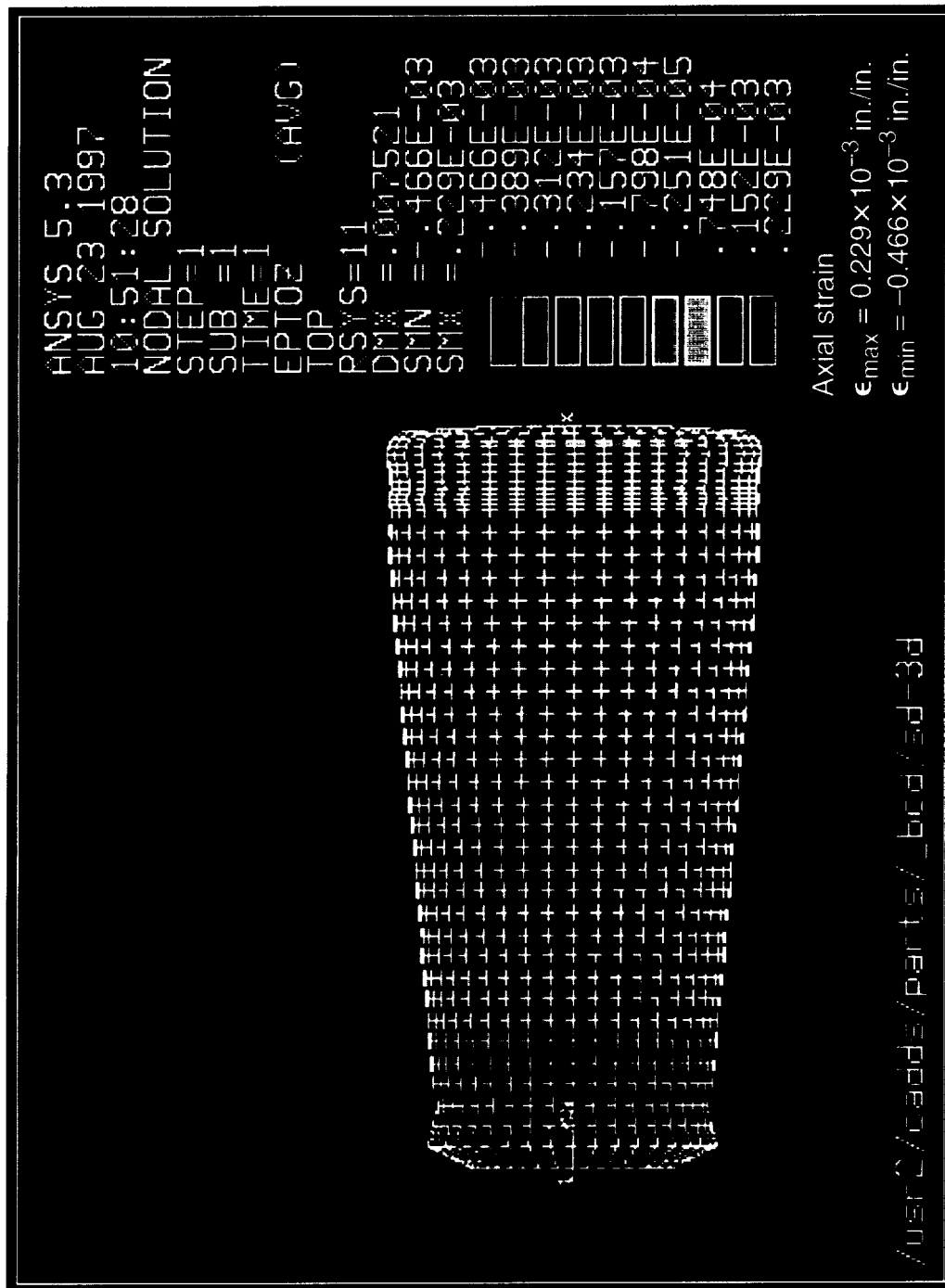


Figure A2.—ANSYS Analysis of AMB-Z1 Surge Duct. (b) Axial strain.

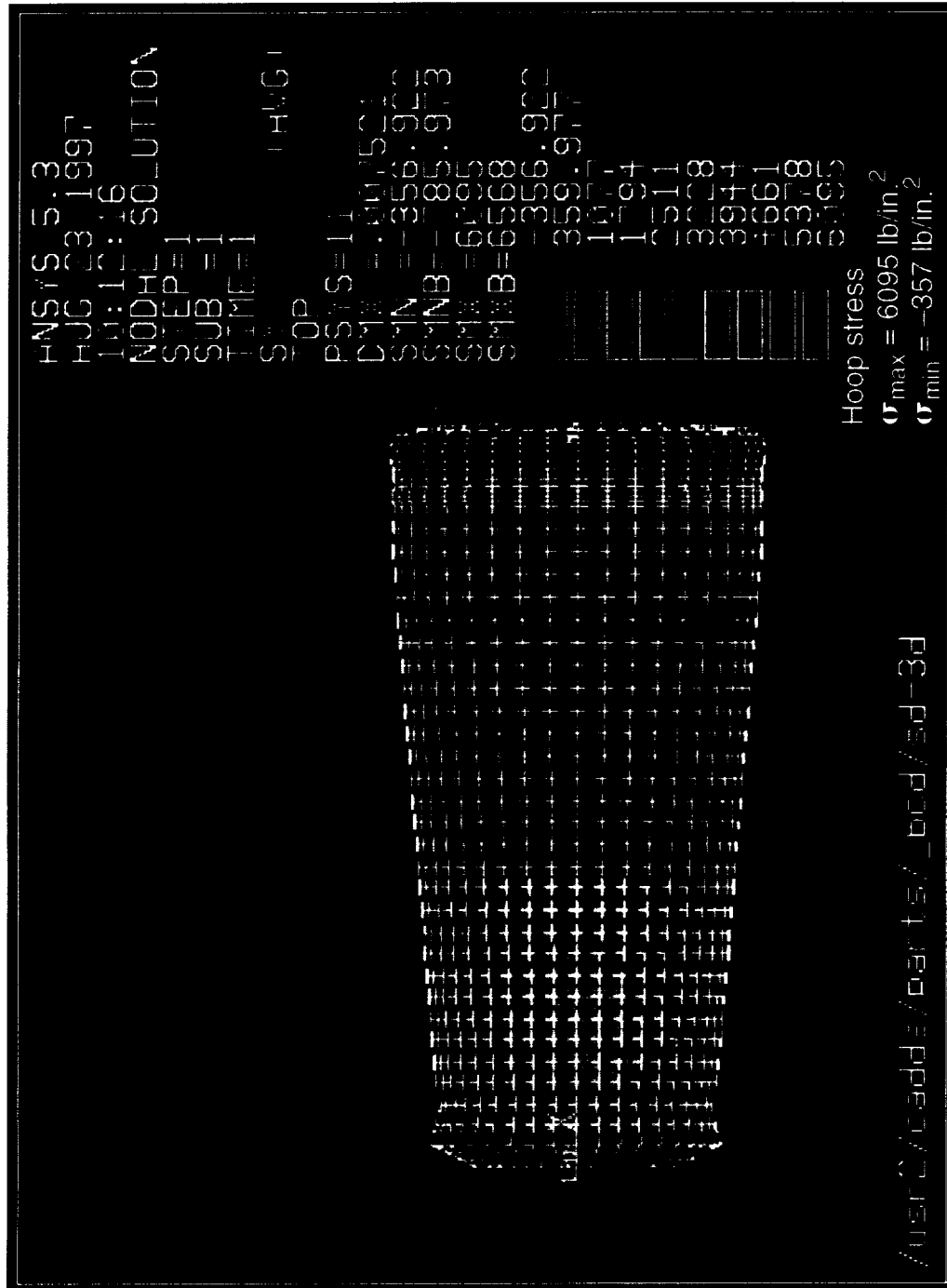


Figure A2.—ANSYS Analysis of AMB-Z1 Surge Duct. (c) Hoop stress.

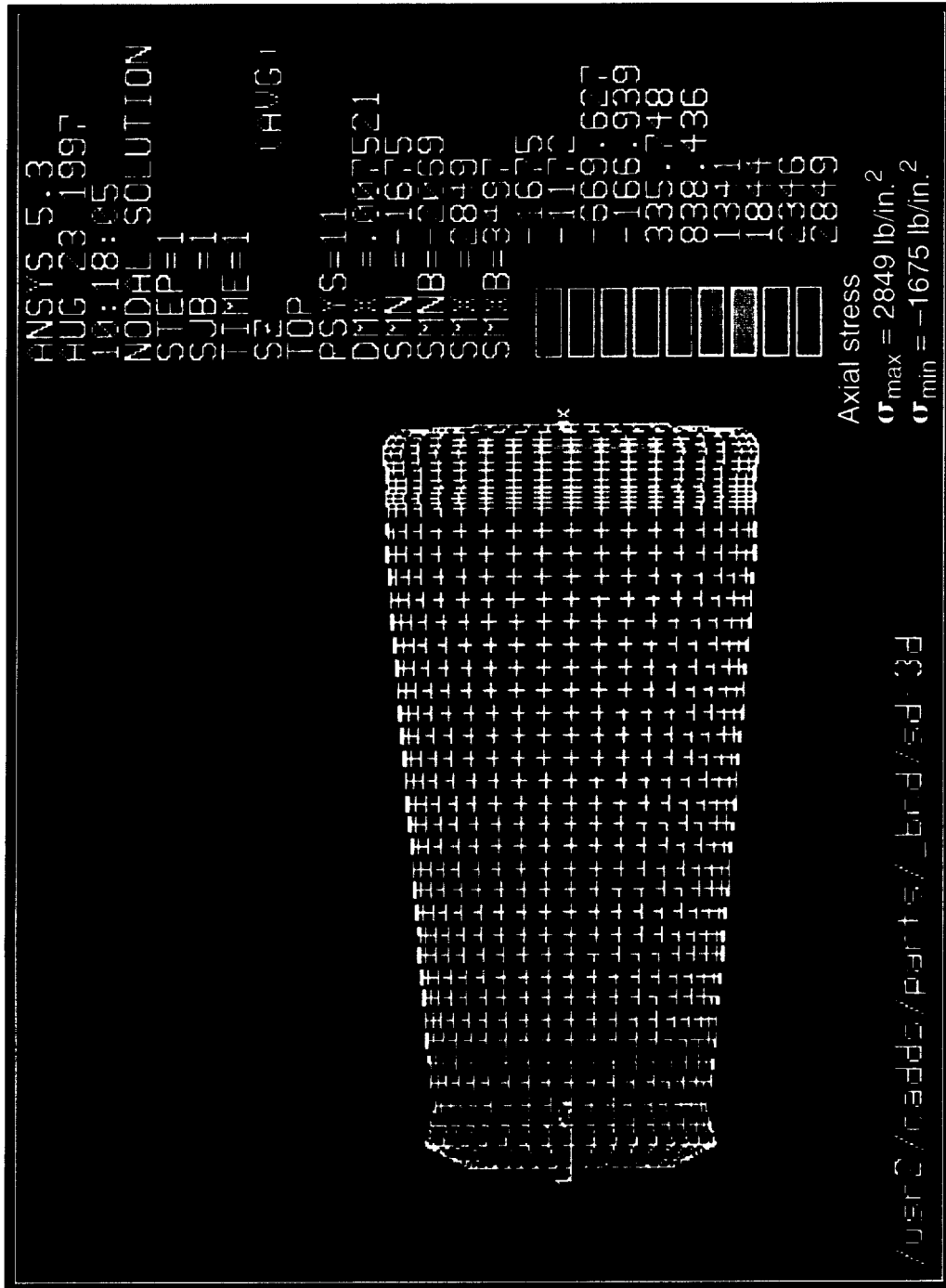


Figure A2.—ANSYS Analysis of AMB-Z1 Surge Duct. (d) Axial stress.

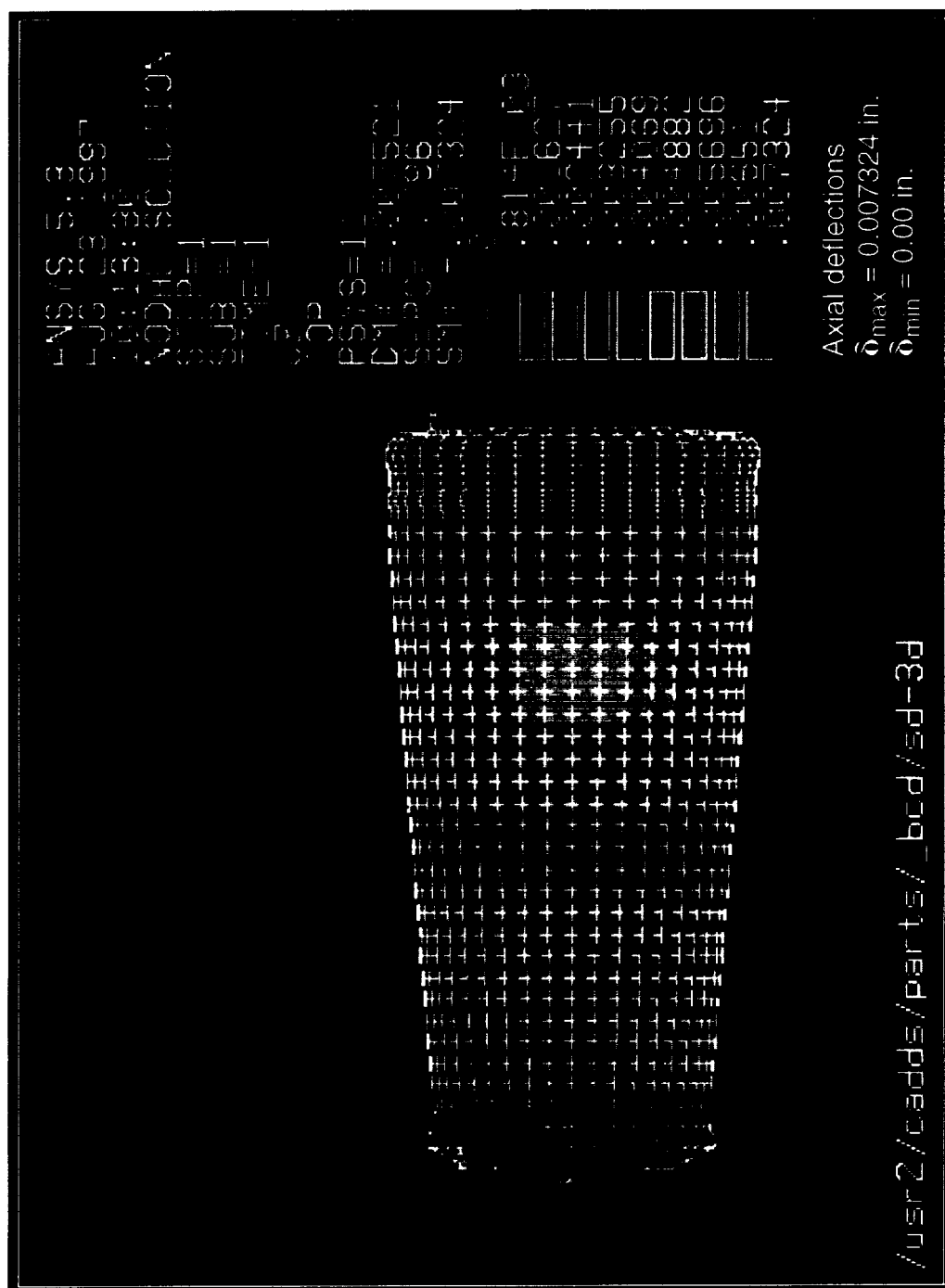


Figure A2.—ANSYS Analysis of AMB-Z1 Surge Duct. (e) Axial deflections.

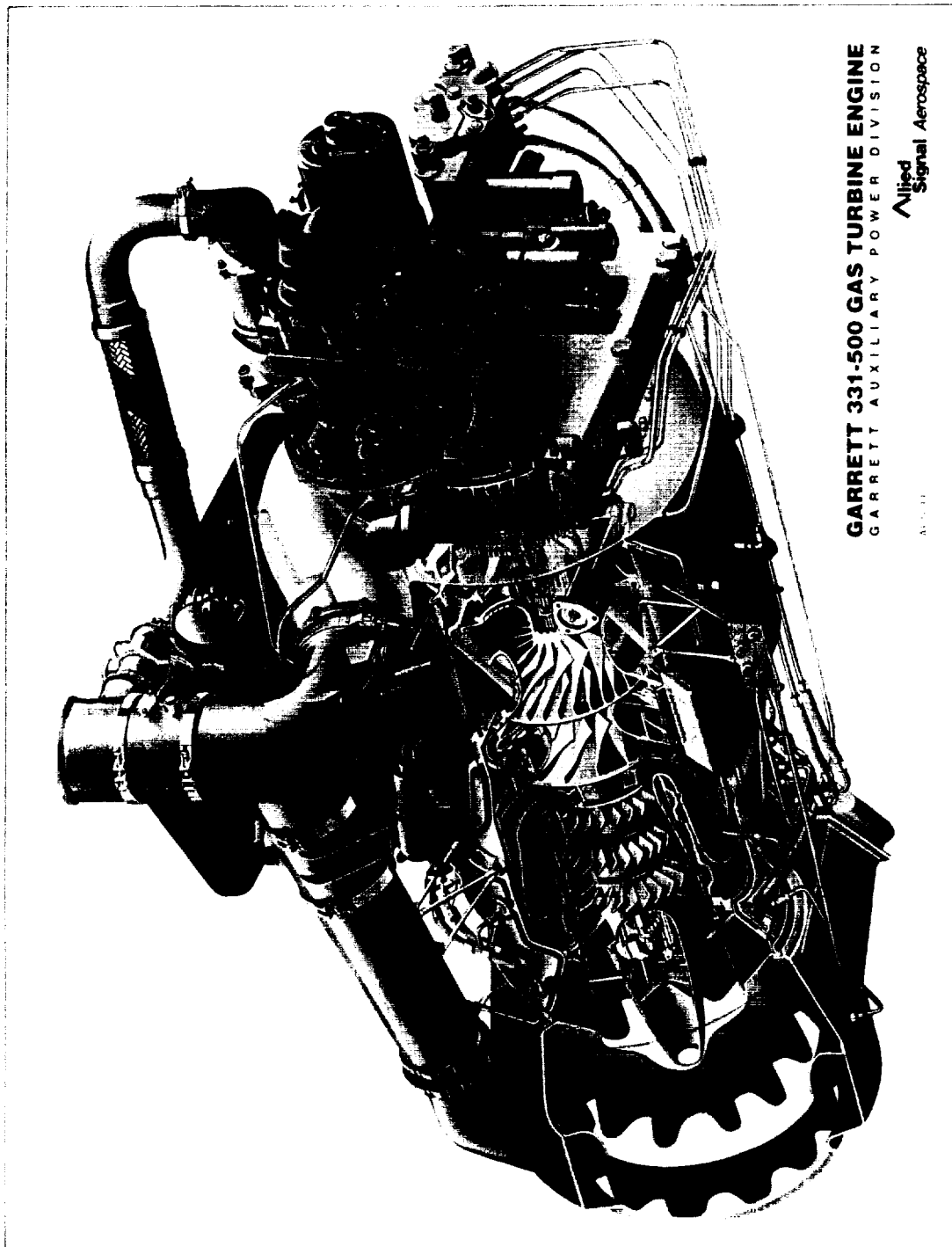


Figure A3.—Allied Signal APU.

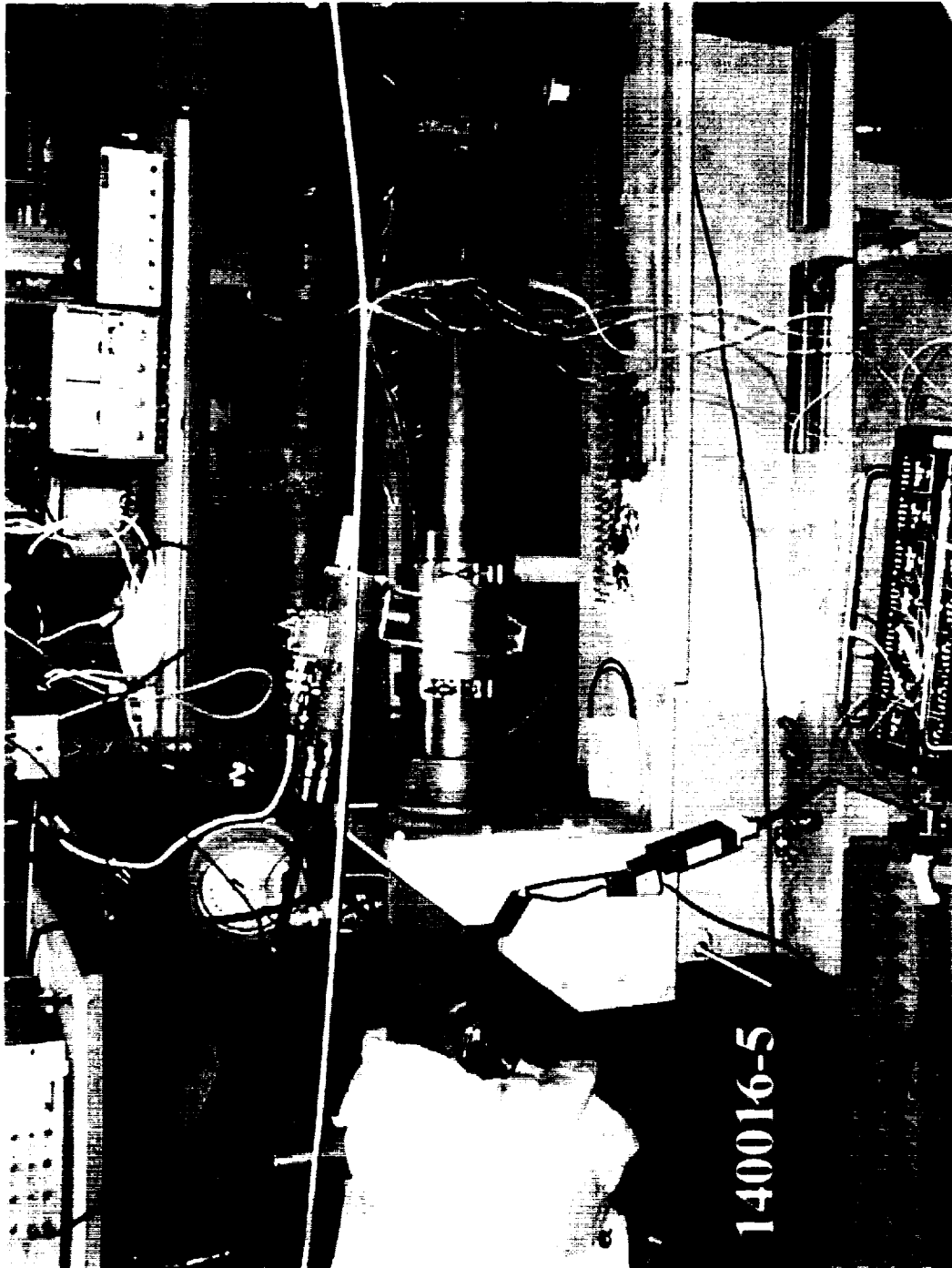


Figure A4a.—Rig test of AMB-21 surge duct.

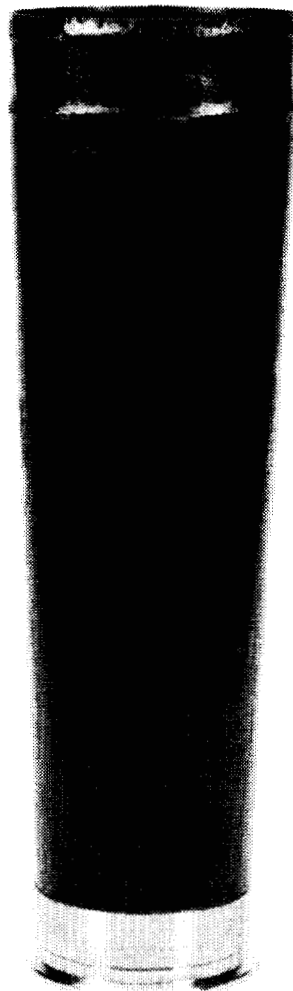


Figure A4b.—Completed AMB-21 surge duct before rig tests.



TEST REPORT

3883 E. Eagle Drive, Anaheim, CA 92807-1722 / Phone 714-630-3003 • Fax 714-630-4443
FAA Repairstation Number OYCR172L

Page 1 of 2

COMPOSITES HORIZONS, INC. 1471 INDUSTRIAL PARK STREET COVINA, CA 91722-3499 ATTN: DENNIS DIEM	OCMTL NO.: 971353
	DATE OF REPORT: 10-13-97
	PURCHASE ORDER NO: 19685
	PHONE: 818-331-0861
	FAX: 818-339-3220

TYPE OF TEST:	FIBER CONTENT OF RESIN MATRIX COMPOSITES BY MATRIX DIGESTION
MATERIAL IDENTIFICATION:	SUPPLIED TEST SAMPLES
LOT/BATCH/SERIAL NO.:	GRAPHITE TUBE
SPECIFICATION/REVISION:	E50TFS36, S-1
TEST PROCEDURE:	ASTM-D-3171
SPECIMEN CONDITIONS:	AS RECEIVED
TEST TEMPERATURE:	75°C
DATE OF TEST:	10-13-97

LD.	SPECIFIC GRAVITY	% RESIN CONTENT	% VOID VOLUME	% FIBER VOLUME
GRAPHITE TUBE	1.62	20.63	4.70	70.57
	1.62	20.53	4.61	70.67
	1.61	22.92	4.21	67.69
AVERAGE:	1.62	21.36	4.51	69.64

REPORTED DENSITIES

Resin Density: 1.19 g/cc
Fiber Density: 1.91 g/cc

This is to certify that the above tests were performed in accordance with the terms of the purchase order requirements.
Test equipment is calibrated with standards traceable to the NIST.


John A. Bruner
Director of Quality

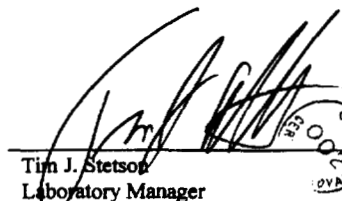

Tim J. Stetson
Laboratory Manager

Figure A5a.—Processing and test data for part #6 of AMB-21 surge duct (page 1).



TEST REPORT

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FAA Repairstation Number OYCR172L

REVISED REPORT: 10-17-97

Page 2 of 2

COMPOSITES HORIZONS, INC.
1471 INDUSTRIAL PARK STREET
COVINA, CA 91722-3499

OCMTL NO.: 971353
DATE OF REPORT: 10-13-97
PURCHASE ORDER NO: 19685
PHONE: 818-331-0861
FAX: 818-339-3220

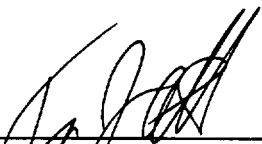
ATTN: RICK PRAFKE

TYPE OF TEST: T_g (BY TMA)
MATERIAL IDENTIFICATION: SUPPLIED TEST SAMPLES
LOT/BATCH/SERIAL NO.: GRAPHITE TUBE
SPECIFICATION/REVISION: E50TF536, S-1
TEST PROCEDURE: ASTM-E-831
SPECIMEN CONDITIONS: 250°F
TEST TEMPERATURE: 25 - 325°C AT 10°C / MINUTE
DATE OF TEST: 10-13-97

LD.	T _g (°C)	LD.	T _g (°C)
GRAPHITE TUBE	241	GRAPHITE TUBE	256
(SMALL TUBE)	244	(LARGE RING)	256
	249		252
AVERAGE:	245	AVERAGE:	255
REQUIREMENTS:	243 - 277°C	REQUIREMENTS:	243 - 277°C

EQUIPMENT:	CONTROL NUMBER:	CALIBRATION DATE:	CALIBRATION DUE DATE:
TMA	1695	09/11/97	-
WEIGHTS	1466	06/01/95	06/01/98

This is to certify that the above tests were performed in accordance with the terms of the purchase order requirements.
Test equipment is calibrated with standards traceable to the NIST.


John A. Bruner
Director of Quality

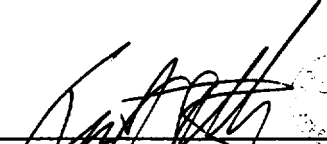

Tim J. Stetson
Laboratory Manager

Figure A5a.—Processing and test data for part #6 of AMB-21 surge duct (page 2).

COMPOSITES HORIZONS, INC. COVINA, CALIFORNIA		MASTER TRAVELER	PART NAME: Allied Signal Surge Duct PART NUMBER: R-3569406.1	
SERIAL NUMBER:		PAGE 3 OF 5		
OP NO.	OPERATION DESCRIPTION	REQUIRED TOOLING	FA	BO
060	Bag for Imidization and cure as follows:		10-4-94	
070	Wrap the part with one layer of high temperature teflon release film and tape in place with Kapton tape. Place one layer of 0.005" steel shim around the lay-up and tape in place with Kapton tape. The shims should be cut into strips along the length and between the ends where the taper begins and the "bumps". The shims should overlap a minimum of 0.1" and a maximum of 0.2". Wrap the lay-up with at least one layer of Kapton shrink tape and tape in place with Kapton tape.		10-4-94	
080	Apply fiberglass breather material and bag with one layer of Kapton using high temperature brown sealant NPO154. (Note: Use at least 2 high temperature thermocouples and a high temperature vacuum port.)		10-4-94	
090	Cover the lay-up with breather material and vacuum bag and imidize and cure as follows: 1) Apply full vacuum and check for leaks. 2) Vent part to atmosphere. 3) Apply 3-5 inches of Hg vacuum. 4) Raise Temperature to 430F ± 10F at 1-3F/minute. 5) Hold at 430F ± 10F for 100 ± 5 minutes. 6) Apply full vacuum. 120 PSI. 7) Apply 200 ± 10 PSI 8) Heat part to 600F ± 10F at 1-3F/minute. 9) Hold at 600F ± 10F for 165 ± 5 minutes. 10) Cool to 100F at 1-10F/minute (Note: Release pressure and vent vacuum when part reaches 400F ± 10F)			

Figure A5a.—Processing and test data for part #6 of AMB-21 surge duct (page 3).

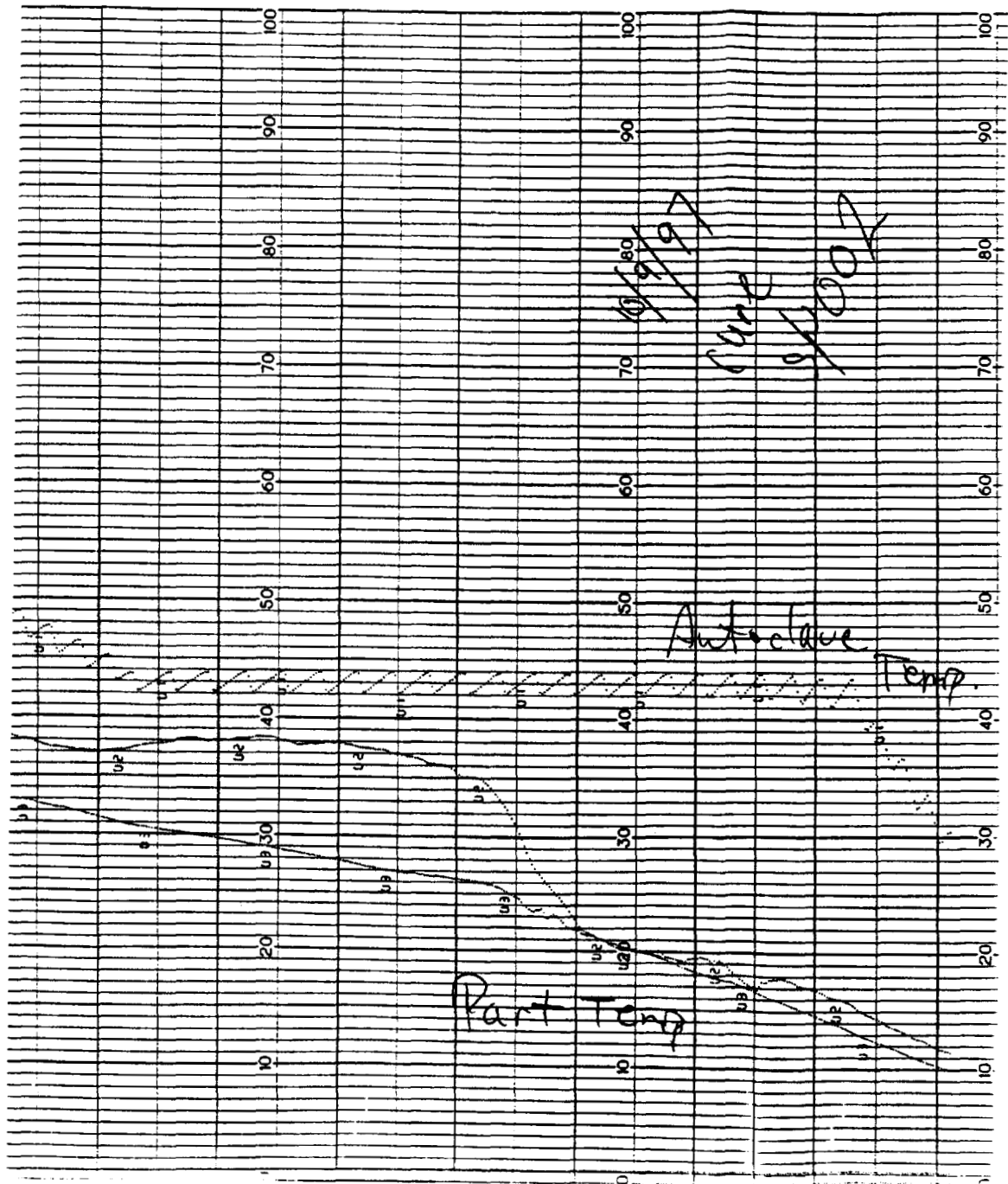


Figure A5a.—Processing and test data for part #6 of AMB-21 surge duct (page 4).

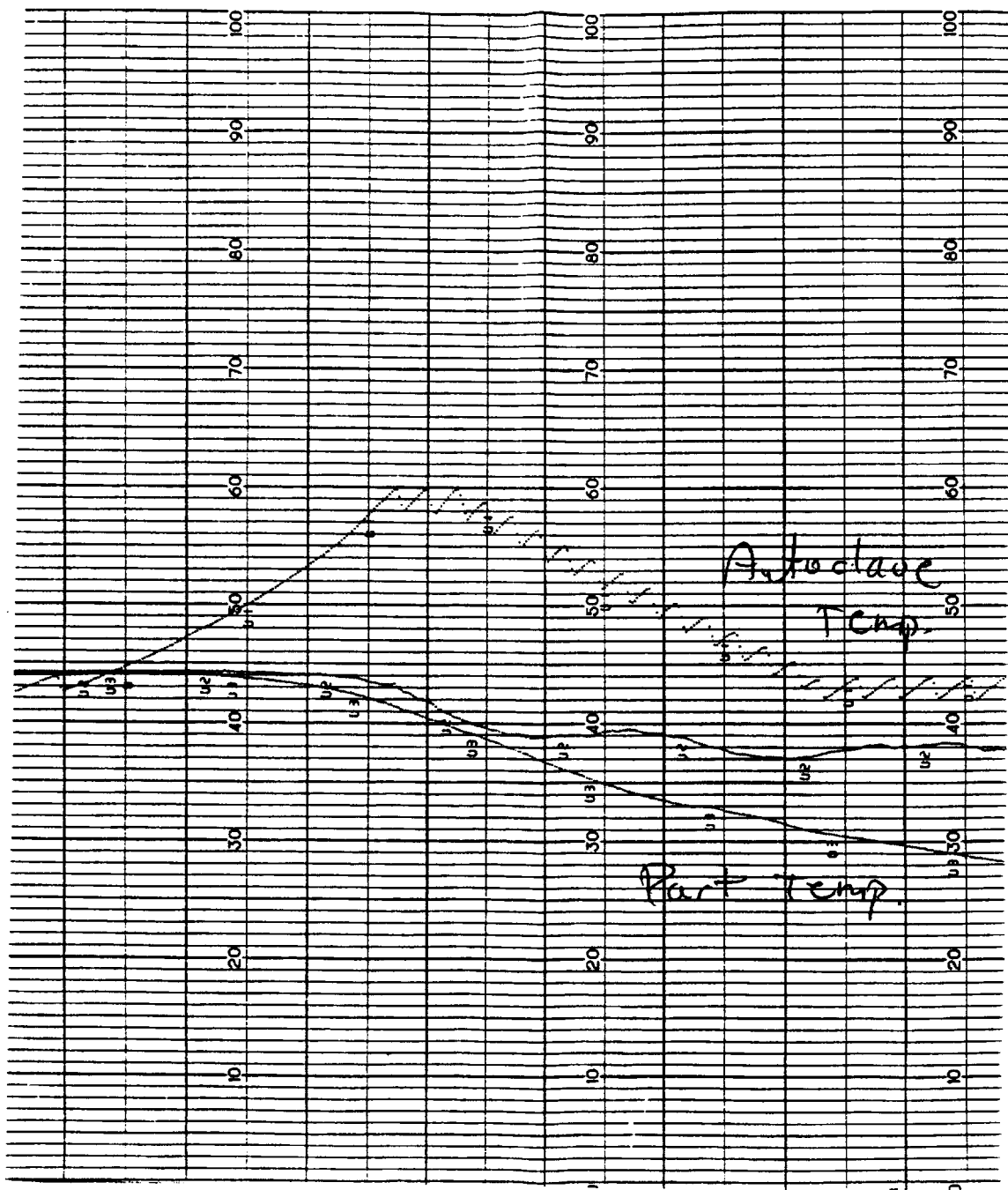


Figure A5a.—Processing and test data for part #6 of AMB-21 surge duct (page 5).

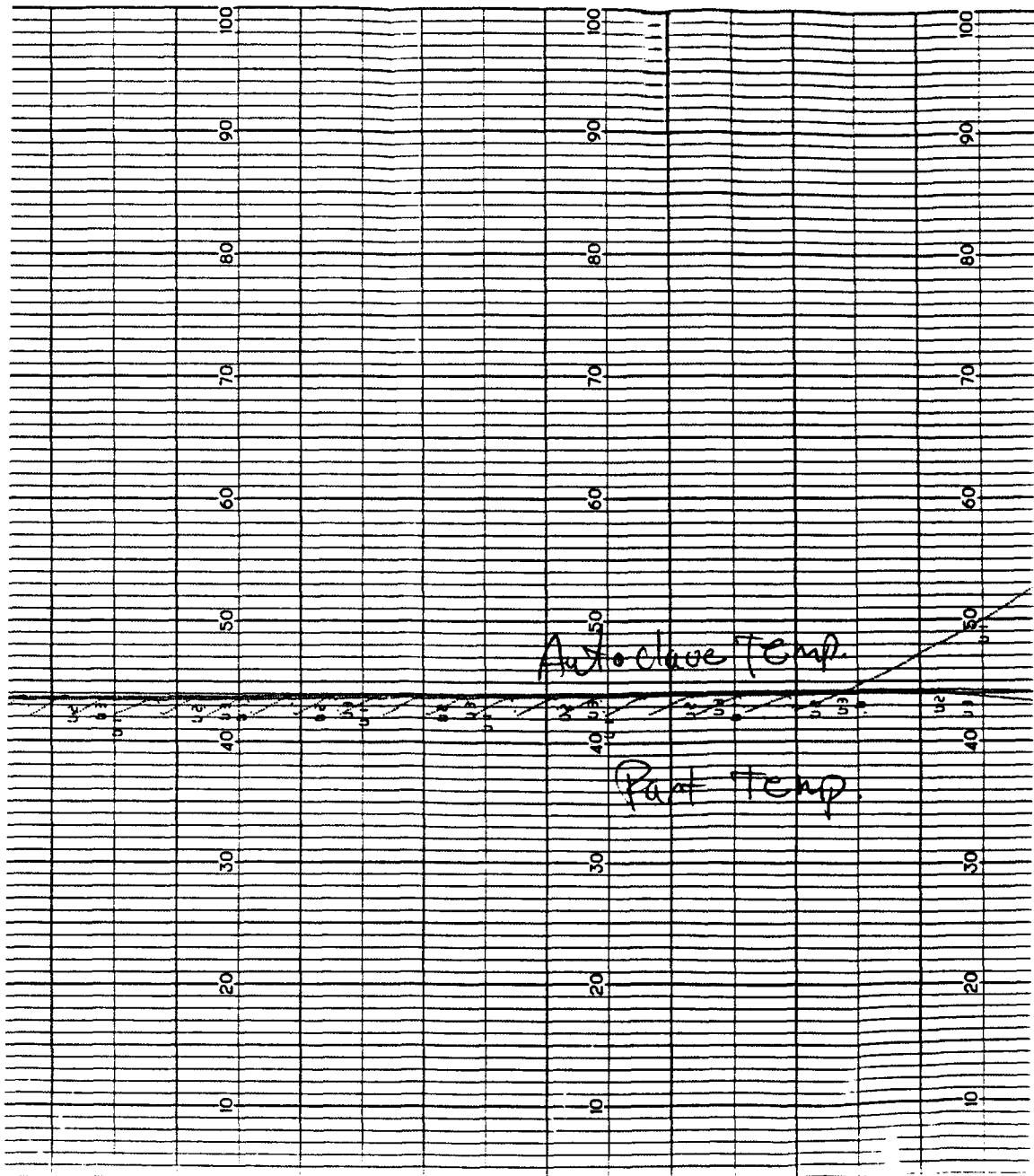


Figure A5a.—Processing and test data for part #6 of AMB-21 surge duct (page 6).

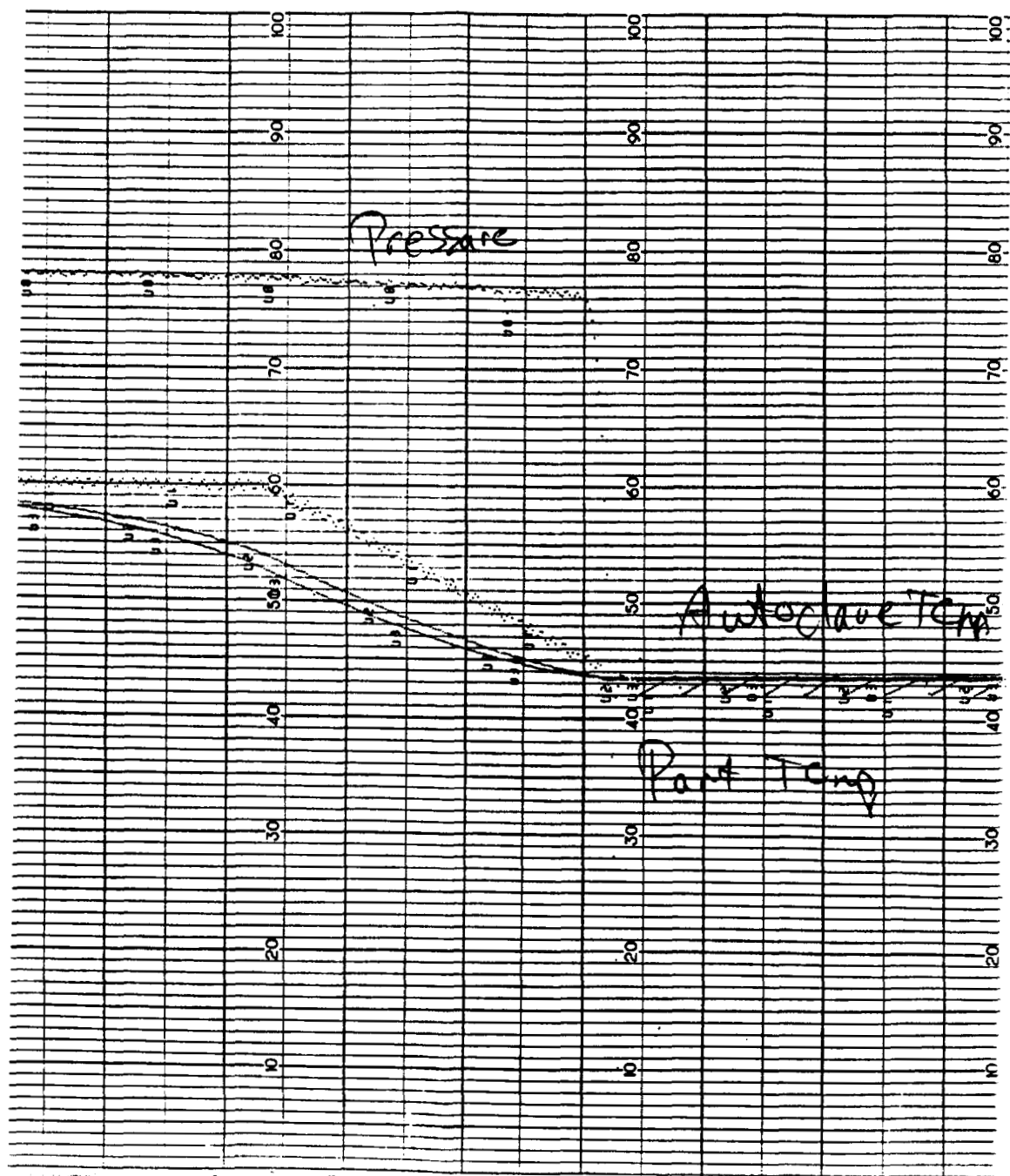


Figure A5a.—Processing and test data for part #6 of AMB-21 surge duct (page 7).

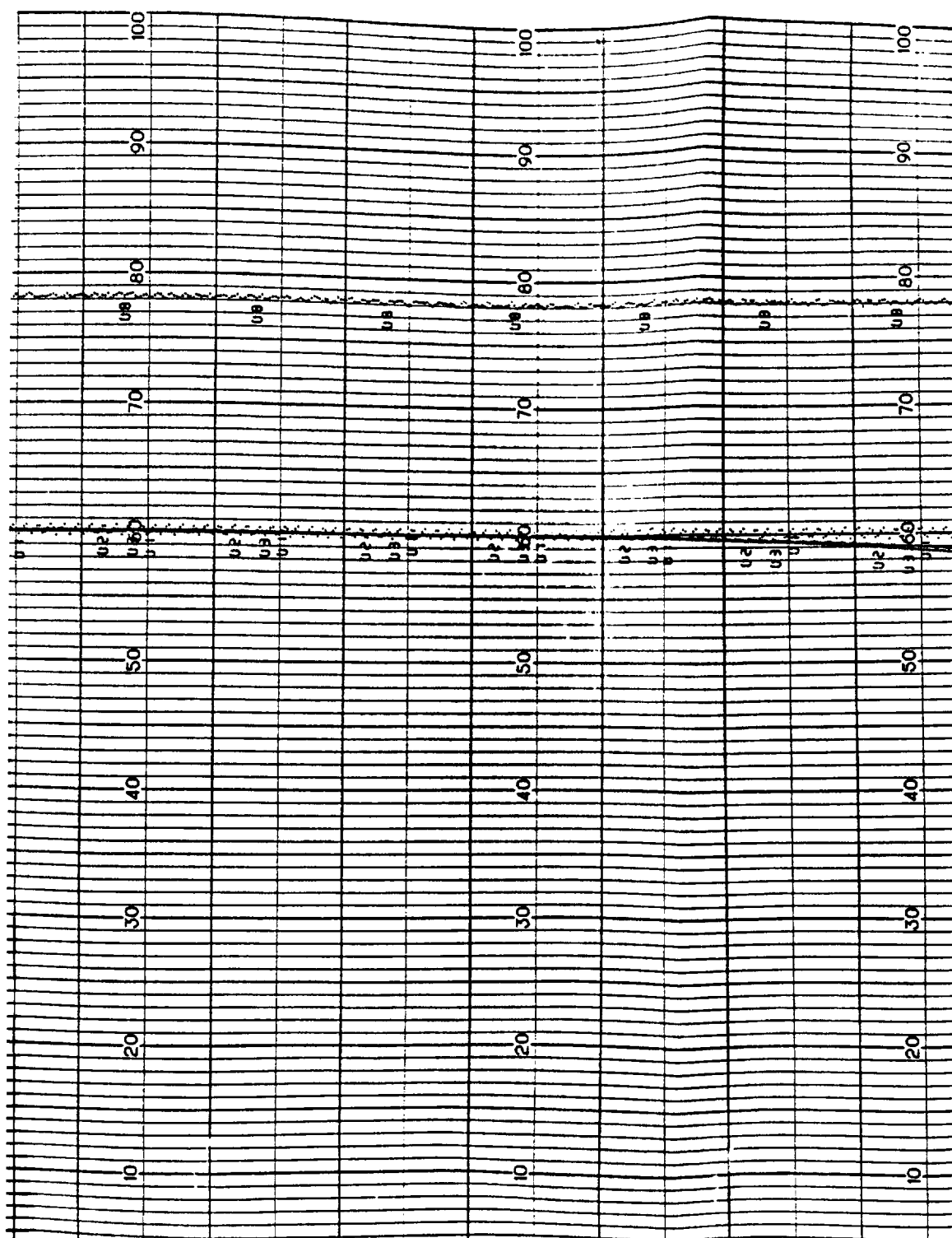


Figure A5a.—Processing and test data for part #6 of AMB-21 surge duct (page 8).

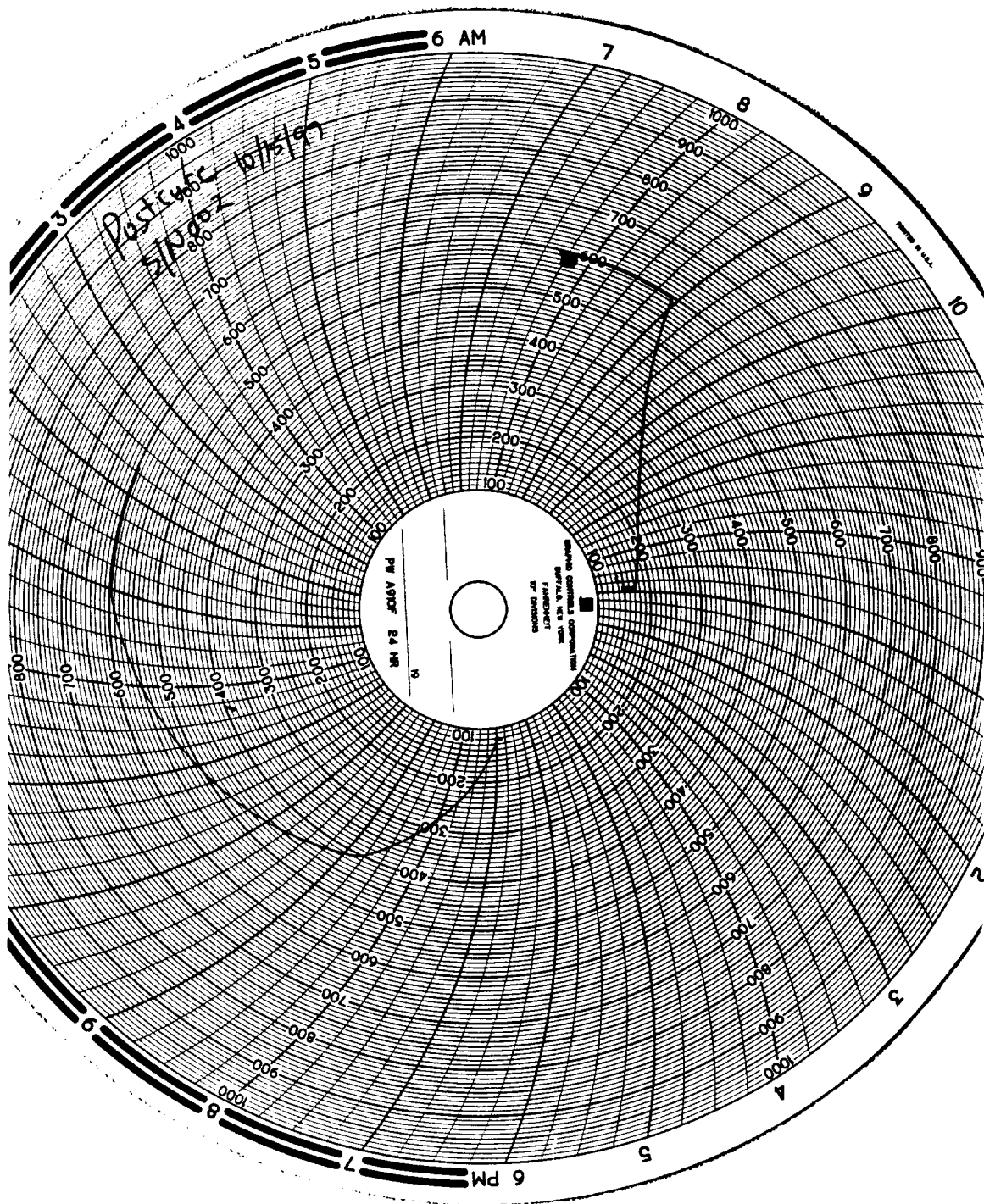


Figure A5a.—Processing and test data for part #6 of AMB-21 surge duct (page 9).

COMPANIES NORVON, INC.
 WILET DUCT
 POP 19634
 STATE (NO) 63187A
 1000-91) KBR/um

NOTE: THE AREA OF TUBE FROM
 THE LG-0 LND TO LEND TAP
 #16 WAS INSULATED USING THE
 CONJOI METHAC AND FENNO
 TO BE ACCEPTABLE

10/1/88
 1/18

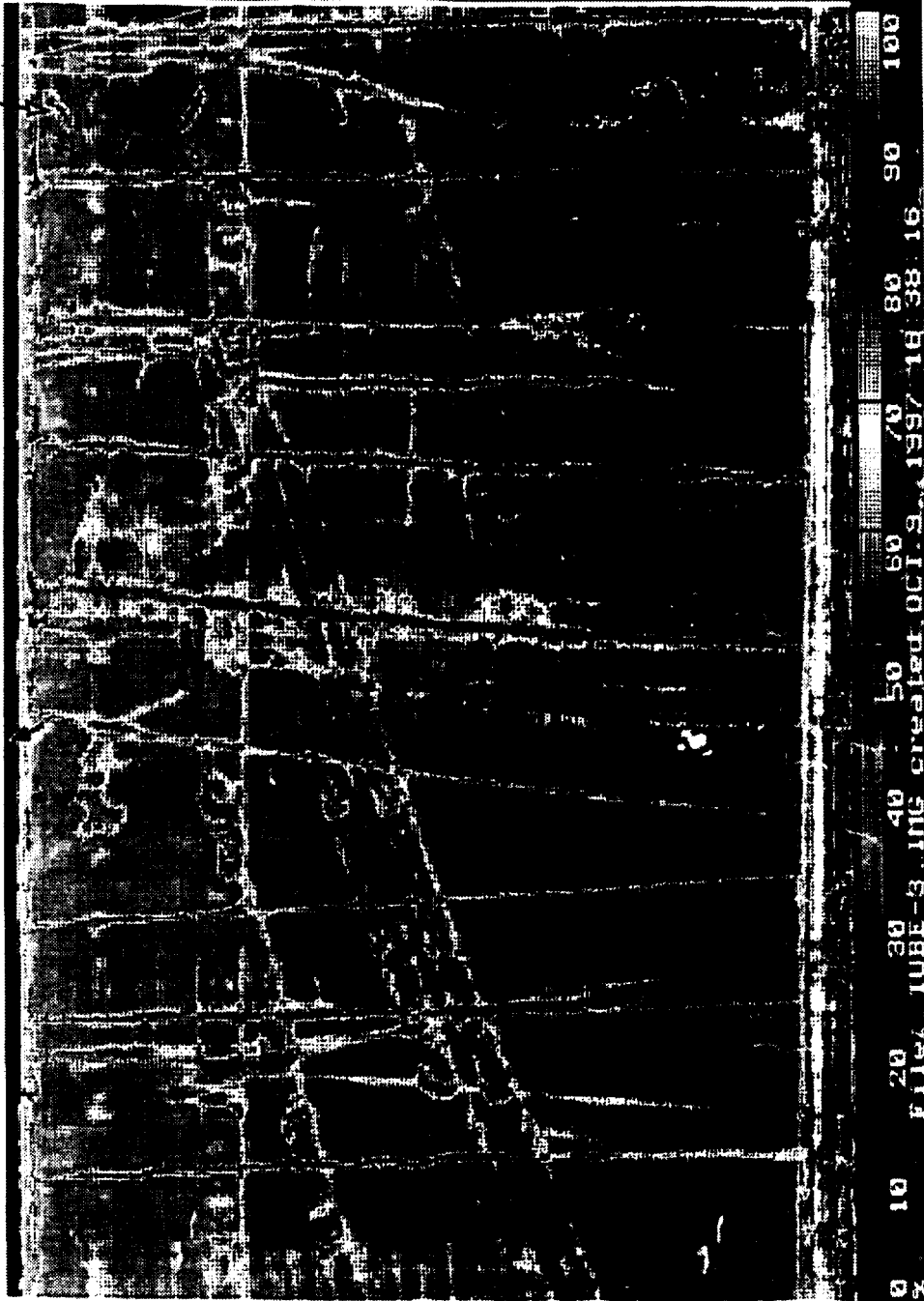


Figure A5a.—Processing and test data for part #6 of AMB-21 surge duct (page 10).



TEST REPORT

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FAA Repairstation Number OYCR172L

Page 1 of 2

COMPOSITES HORIZONS, INC
1471 INDUSTRIAL PARK STREET
COVINA CA 91722-3499

OCMTL NO.: 980183
DATE OF REPORT: 2-9-98
PURCHASE ORDER NO: 98-451
PHONE: 213-587-1342
FAX: 213-587-1814

ATTN: RANDY MAY

TYPE OF TEST: RESIN CONTENT BY MATRIX DIGESTION
MATERIAL IDENTIFICATION: P/N # R3559406 S/N # 004 BATCH # 5304 ROLL # 2
LOT/BATCH/SERIAL NO.: GRAPHITE COMPOSITES RINGS
SPECIFICATION/REVISION: ES0TF536 S-1
TEST PROCEDURE: ASTM-D-3171
SPECIMEN CONDITIONS: AS RECEIVED
TEST TEMPERATURE: 73°F
DATE OF TEST: 2-6-98

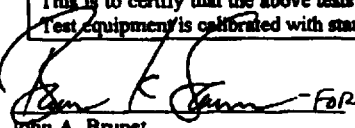
TEST NO.	LOT NO.	SPECIFIC GRAVITY	% RESIN CONTENT	% VOID VOLUME	% FIBER VOLUME
1	304	1.58	34.81	8.50	54.73
2	304	1.53	34.80	2.70	53.86
3	304	1.55	34.72	1.93	53.95
AVERAGE:		1.55	34.51	1.73	54.18

REPORTED DENSITIES

Resin Density 1.19 → 1.25 g/cc

Fiber Density 1.91 → 1.77 "

This is to certify that the above tests were performed in accordance with the terms of the purchase order requirements.
Test equipment is calibrated with standards traceable to the NIST.


John A. Brunet
Director of Quality


Tim J. Stetson
Laboratory Manager

Figure A5b.—Processing and test data for part #7 of AMB-21 surge duct (page 1).



TEST REPORT

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FAA Repairstation Number OYCR172L

Page 2 of 2

COMPOSITES HORIZONS, INC
1471 INDUSTRIAL PARK STREET
COVINA CA 91722-3499

OCMTL NO.: 980183
DATE OF REPORT: 2-9-98
PURCHASE ORDER NO: 98-451
PHONE: 213-587-1342
FAX: 213-587-1814

ATTN: RANDY MAY

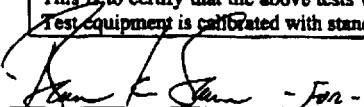
TYPE OF TEST: Glass Transition Temperature (T_g)
MATERIAL IDENTIFICATION: GRAPHITE COMPOSITE RINGS
LOT/BATCH/SERIAL NO.: P/N # R3559406 S/N # 004 BATCH # 5304 ROLL # 2
SPECIFICATION/REVISION: E50TF536 S-1
TEST PROCEDURE: ASTM-E-831
SPECIMEN CONDITIONS: AS RECEIVED
TEST TEMPERATURE: 25°C / 10°C / 425°C
DATE OF TEST: 2-6-98

TEST RESULTS

SAMPLE ID	T _g
1	287°C
2	279°C
3	281°C
Average	282°C

EQUIPMENT:	CONTROL NUMBER:	CALIBRATION DATE:	CALIBRATION DUE DATE:
TMA	1922	1-26-98	2-9-98

This is to certify that the above tests were performed in accordance with the terms of the purchase order requirements.
Test equipment is calibrated with standards traceable to the NIST.


John A. Brunet
Director of Quality

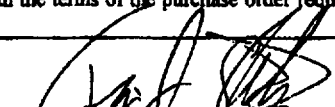

Tim J. Stetson
Laboratory Manager

Figure A5b.—Processing and test data for part #7 of AMB-21 surge duct (page 2).

COMPOSITES HORIZONS, INC. COVINA, CALIFORNIA		MASTER TRAVELER	PART NAME: Allied Signal Surge Duct PART NUMBER: R-3559406-1	
SERIAL NUMBER:		PAGE 3 OF 5		
OP NO.	OPERATION DESCRIPTION	REQUIRED TOOLING	FA	BO
060	Bag for imidization and cure as follows:			
070	Wrap the part with one layer of high temperature teflon release film and tape in place with Kapton tape. Place one layer of 0.005" steel shim around the lay-up and tape in place with Kapton tape. The shims should be cut into strips along the length and between the ends where the taper begins and the "bumps". The shims should overlap a minimum of 0.1" and a maximum of 0.2". Wrap the lay-up with at least one layer of Kapton shrink tape and tape in place with Kapton tape.			
080	Apply fiberglass breather material and bag with one layer of Kapton using high temperature brown sealant NPO154. (Note: Use at least 2 high temperature thermocouples and a high temperature vacuum port.)			
090	Cure as follows: 1) Apply full vacuum and check for leaks. 2) Vent part to atmosphere: ✓ 3) Apply 3-5 inches of Hg vacuum. ✓ 4) Raise Temperature to 420F ± 10F at 1-3F/minute. ✓ 5) Hold at 420F ± 10F for 120 ± 5 minutes. (2:40) 6) Apply full vacuum. ✓ 7) Apply 200 ± 10 PSI pressure 8) Heat part to 600F ± 10F at 1-3F/minute. 9) Hold at 600F ± 10F for 165 ± 5 minutes. 10) Cool to 100F at 1-10F/minute (Note: Release pressure and vent vacuum when part reaches 400F ± 10F)		Done 4-24-99	

Figure A5b.—Processing and test data for part #7 of AMB-21 surge duct (page 3).

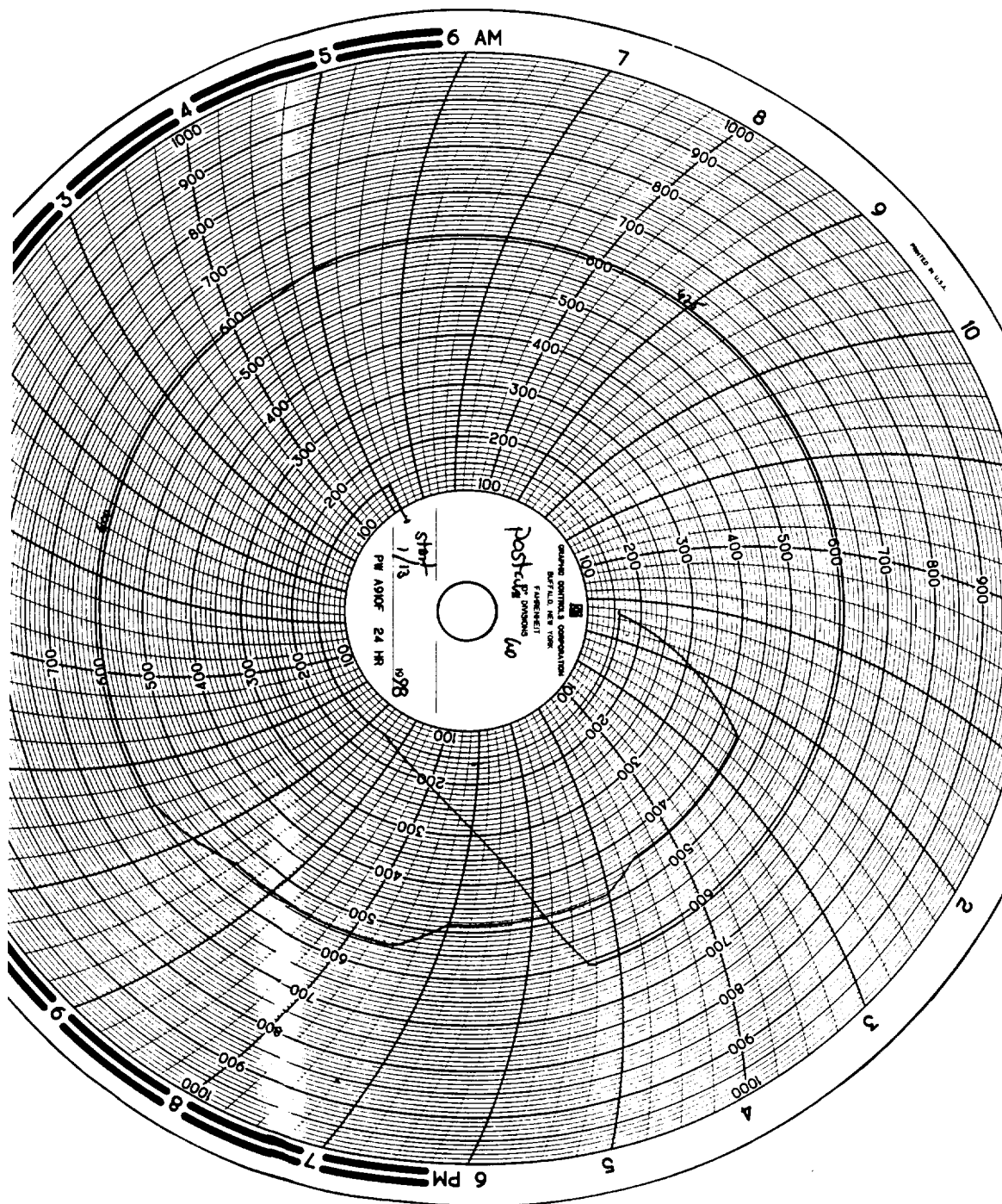


Figure A5b.—Processing and test data for part #7 of AMB-21 surge duct (page 4).

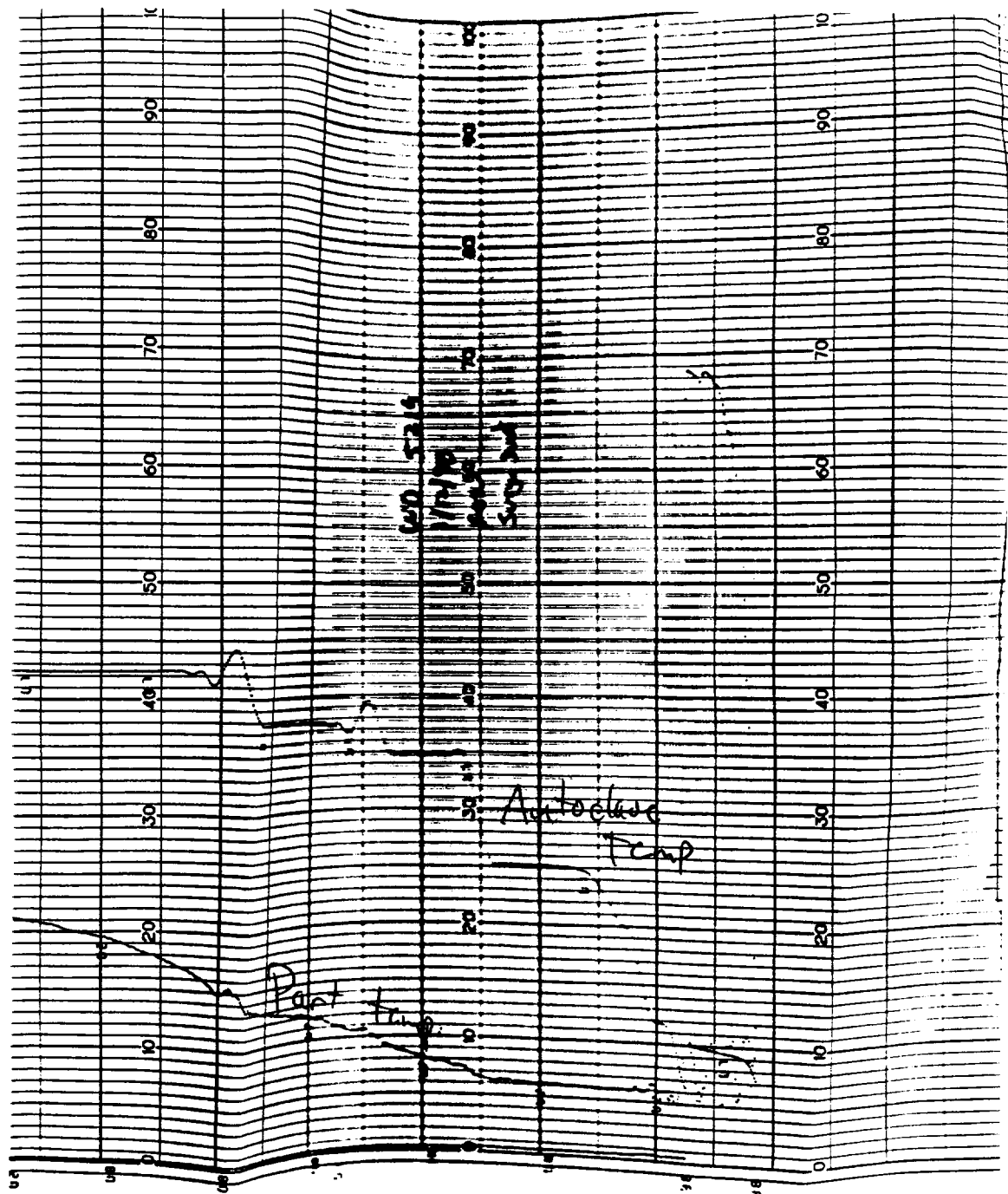


Figure A5b.—Processing and test data for part #7 of AMB-21 surge duct (page 5).

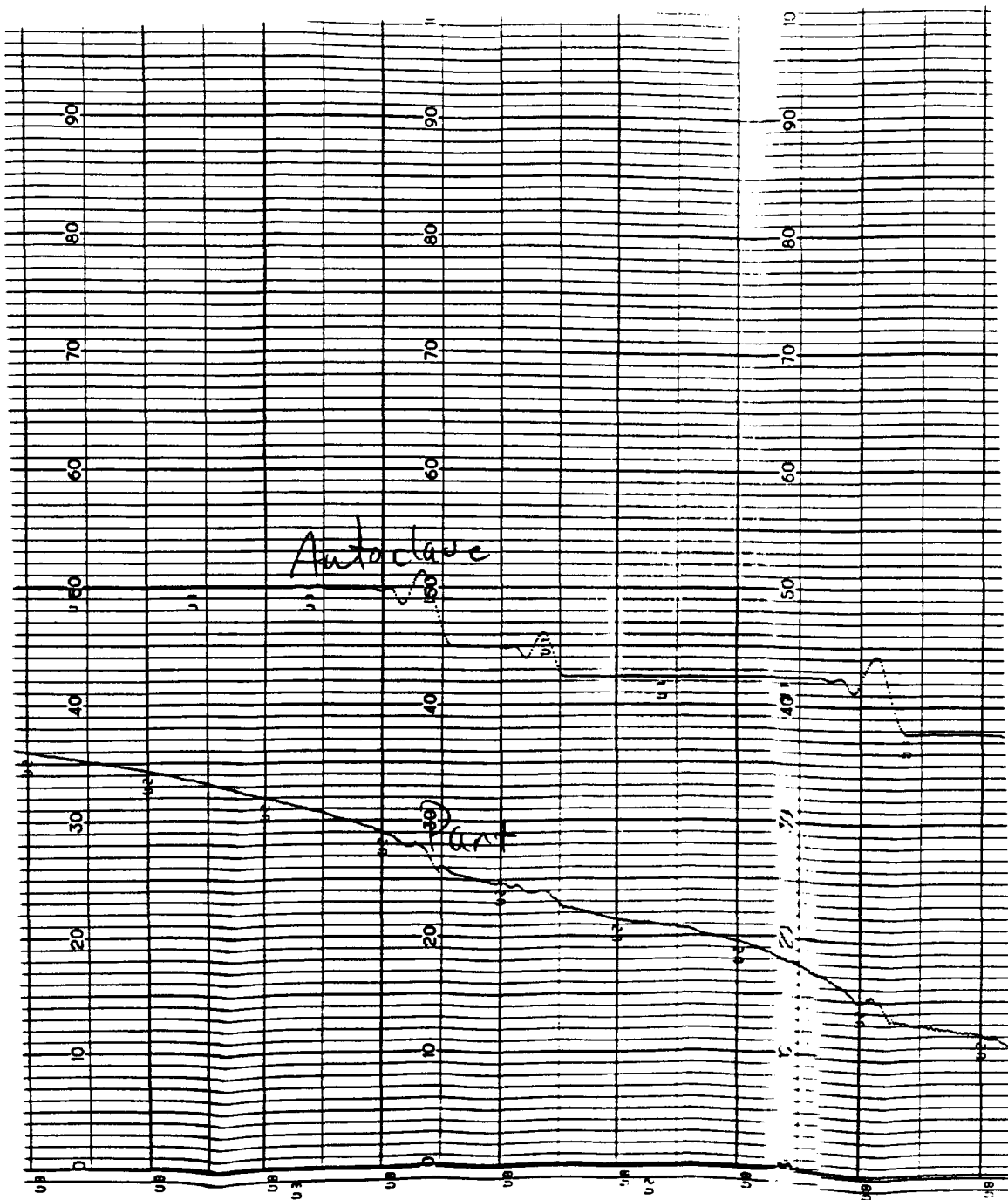


Figure A5b.—Processing and test data for part #7 of AMB-21 surge duct (page 6).

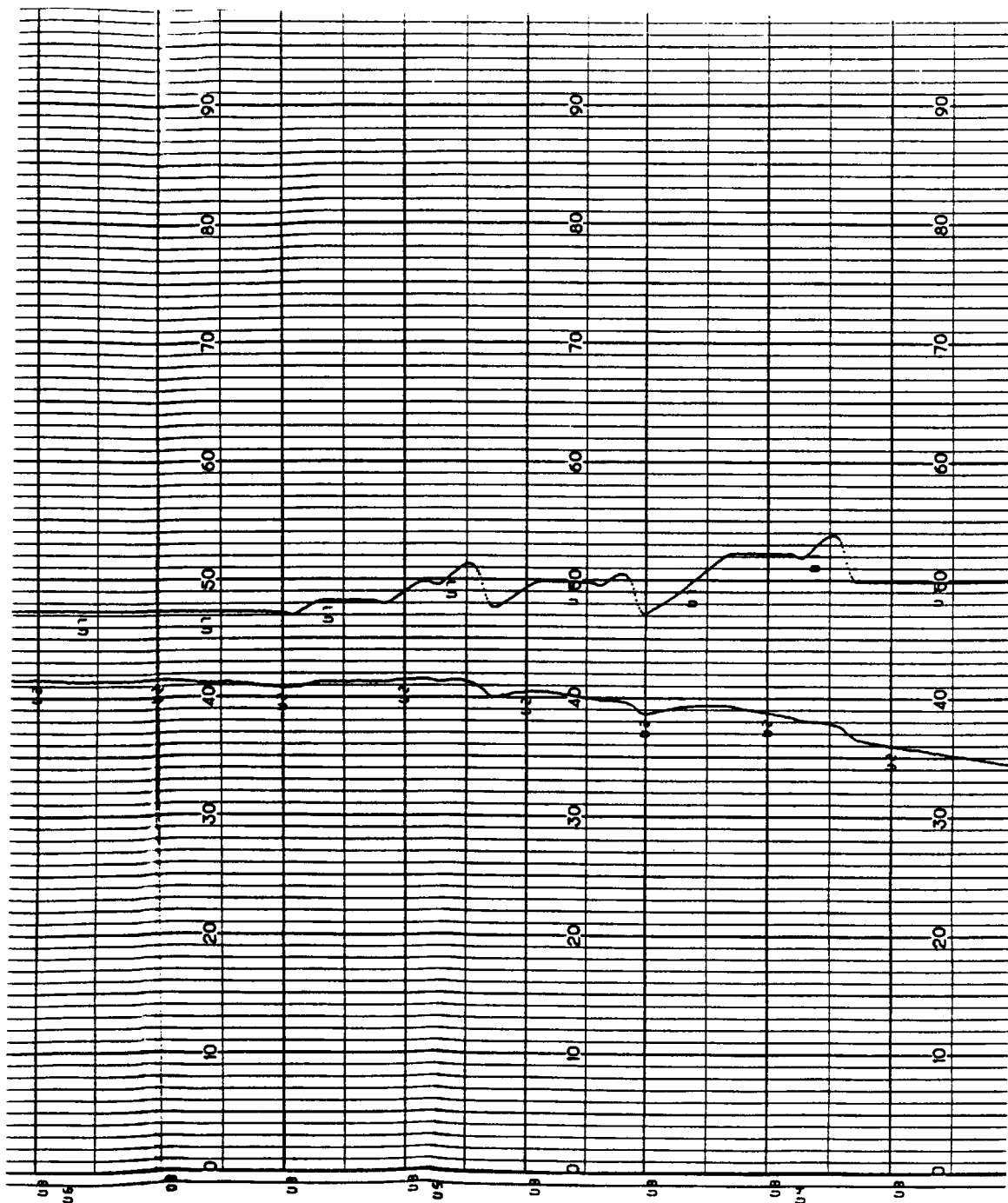


Figure A5b.—Processing and test data for part #7 of AMB-21 surge duct (page 7).

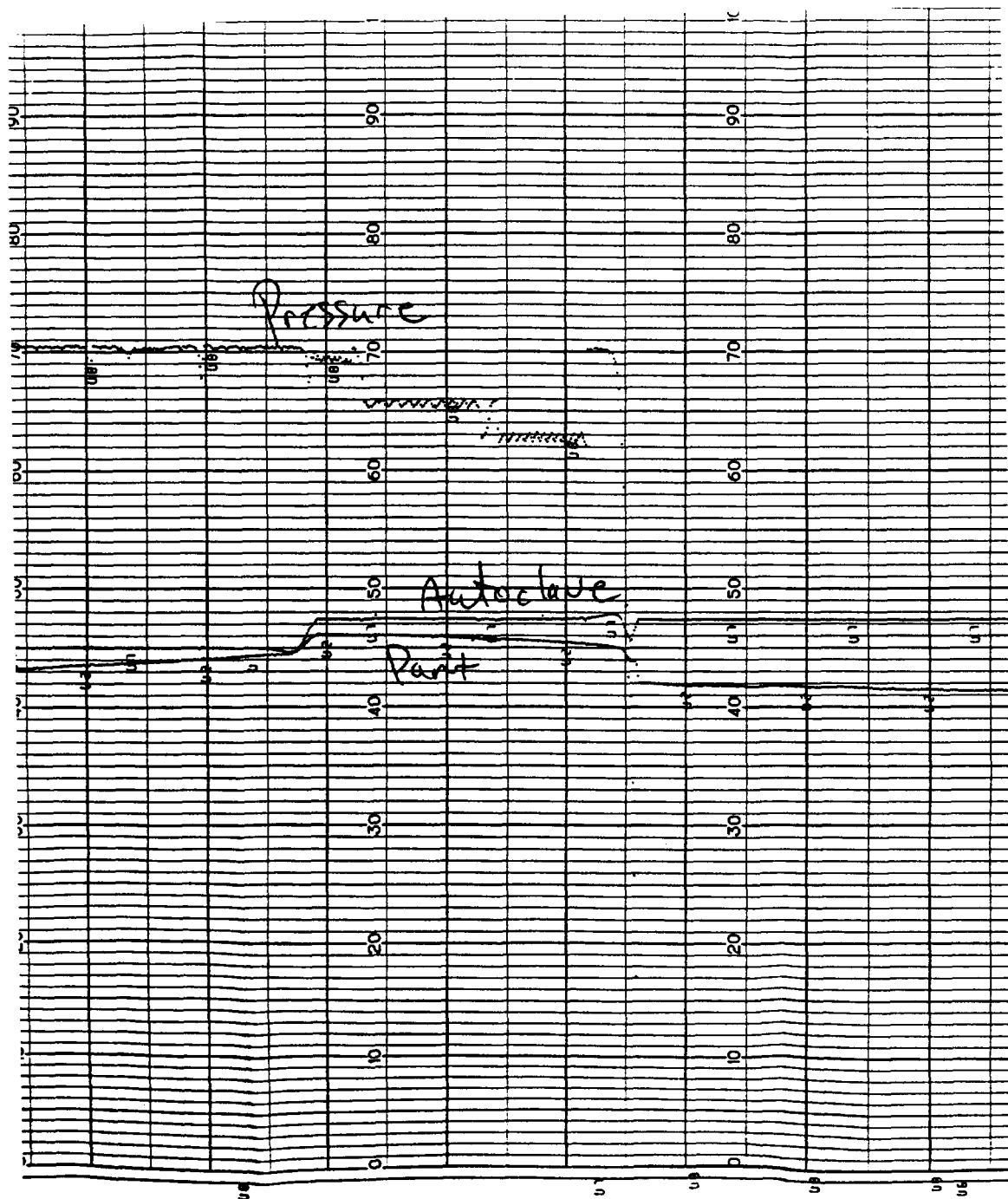


Figure A5b.—Processing and test data for part #7 of AMB-21 surge duct (page 8).

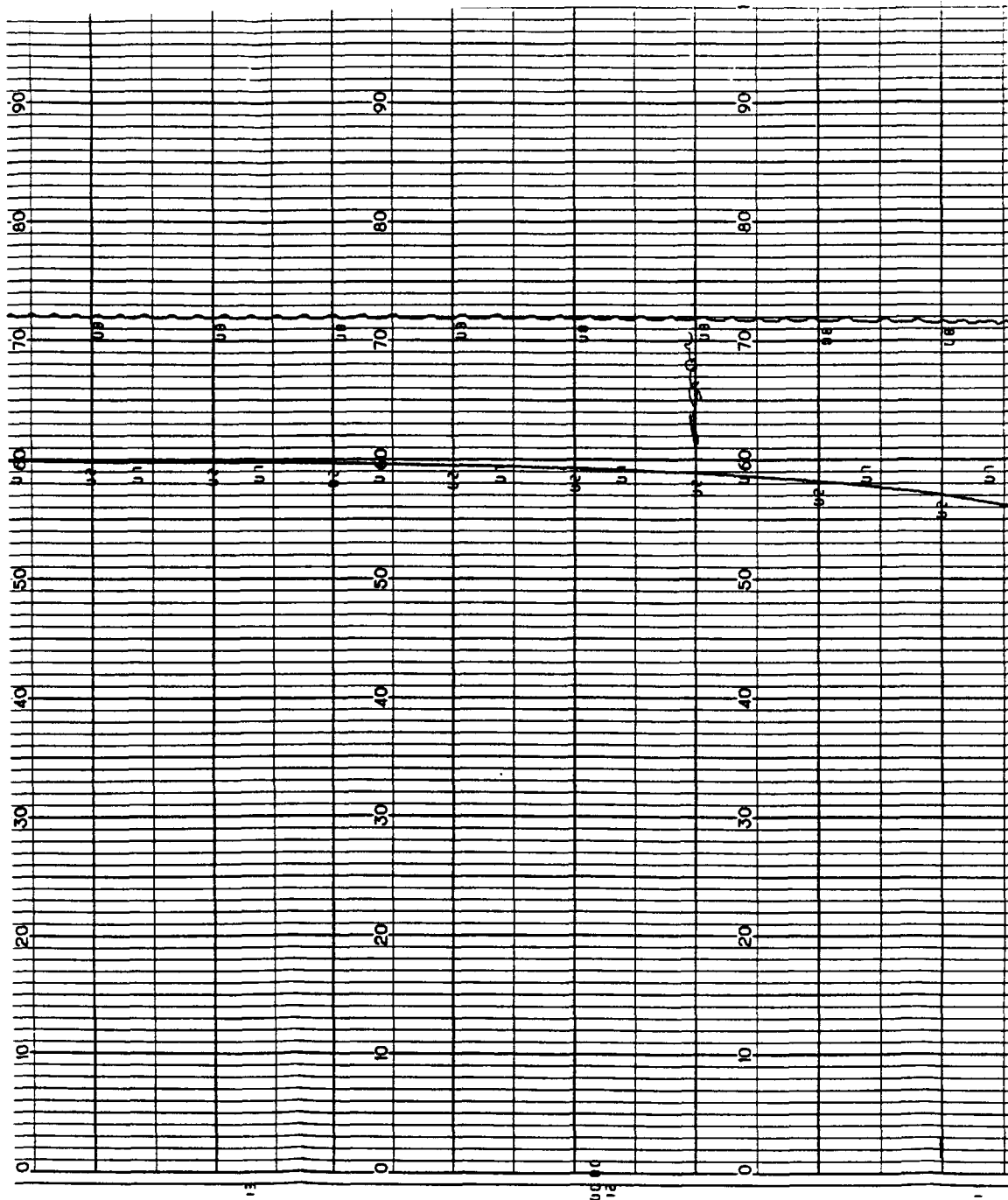


Figure A5b.—Processing and test data for part #7 of AMB-21 surge duct (page 10).

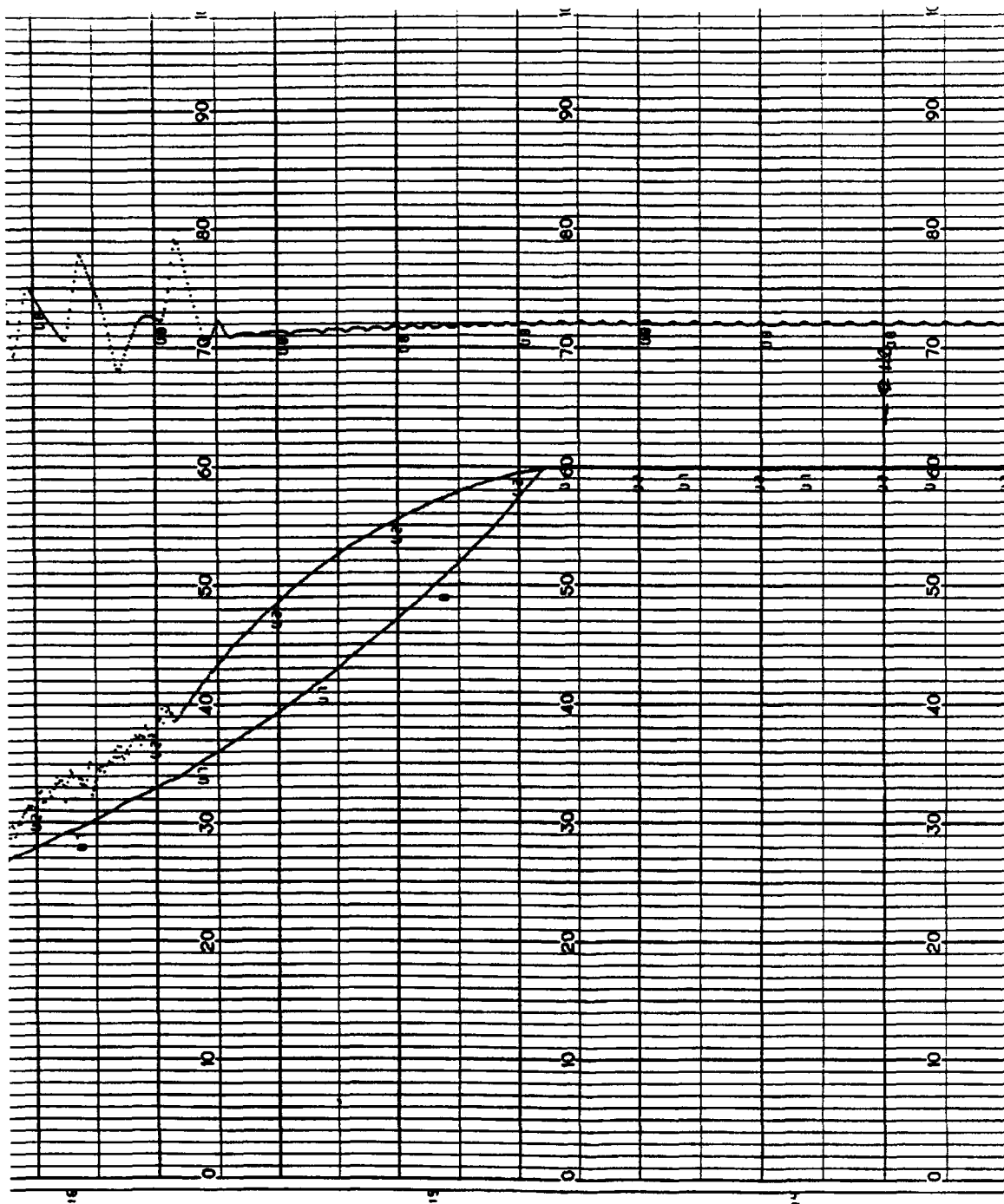


Figure A5b.—Processing and test data for part #7 of AMB-21 surge duct (page 11).

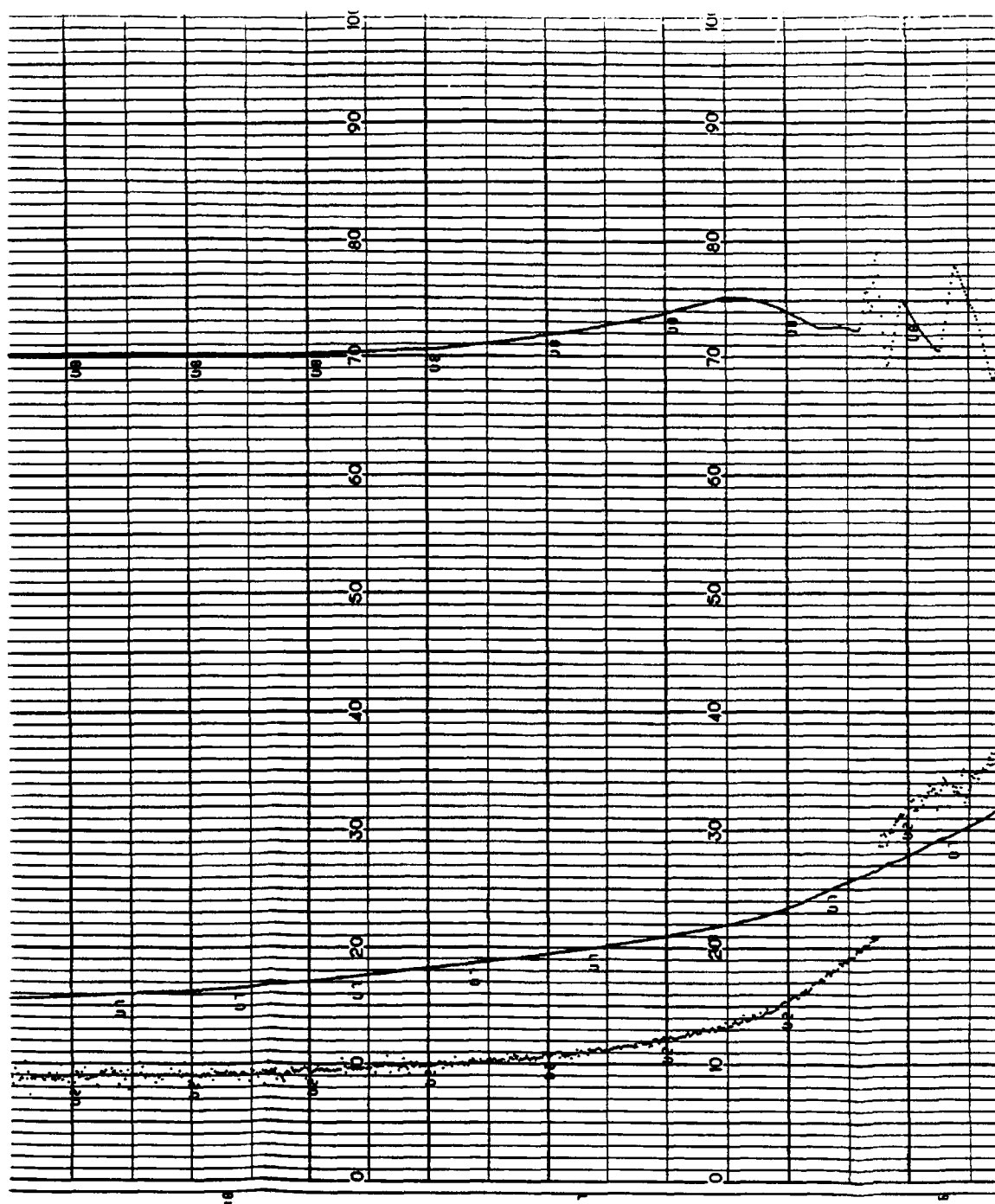


Figure A5.—Processing and test data for Port #7 of AMB-21 surge duct (page 12).

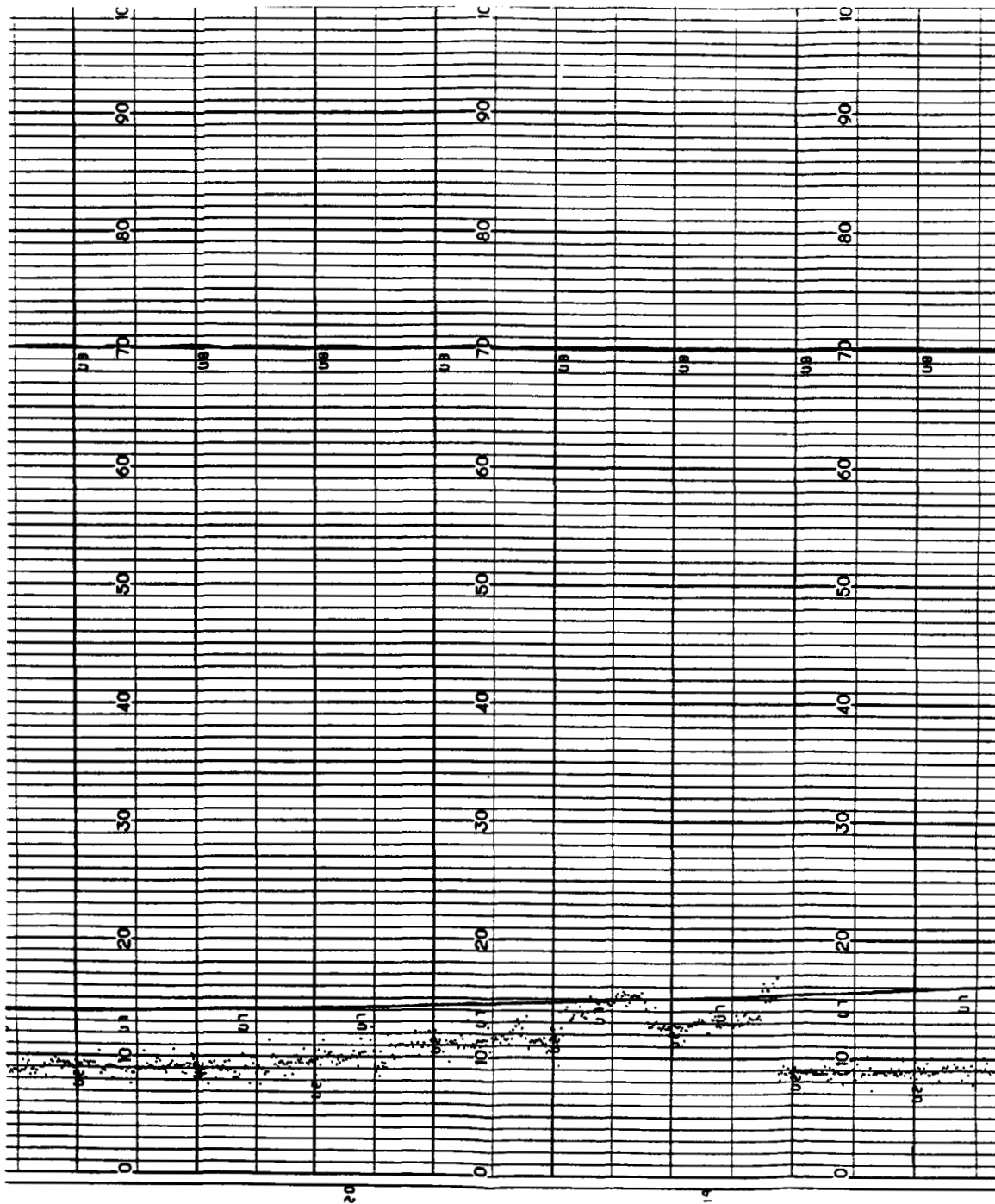


Figure A5b.—Processing and test data for part #7 of AMB-21 surge duct (page 13).

6 FEB 98
 -Saw 1st 2

NOTE: TIME FROM LEAD TIME #3
 TO THE LEAD TIME WAS INDICATED
 BY THE CAPTAIN METERS, WHO FOUND
 NO CONTAINMENT INDICATIONS

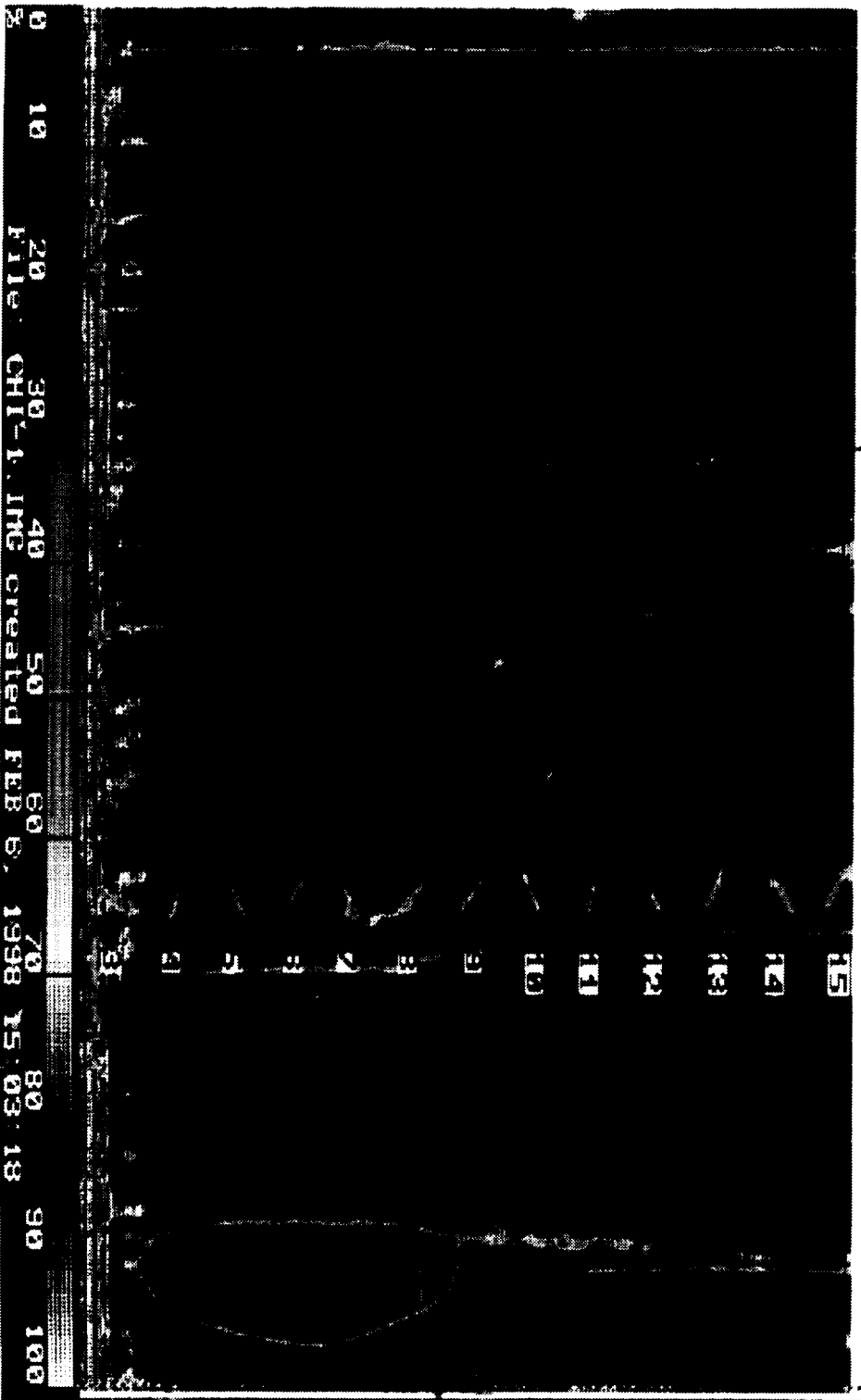


Figure A5.—Processing and test data for Port #7 of AMB-21 surge duct (page 14).

Jan 20 2

NOTE: THE AREA FROM LEAD TIME # 20
TO THE S.M. OF LEAD WAS IDENTIFIED
BY THE CONTACT METHOD AS BEING
TO CONTAIN NO SIGNIFICANT INFORMATION

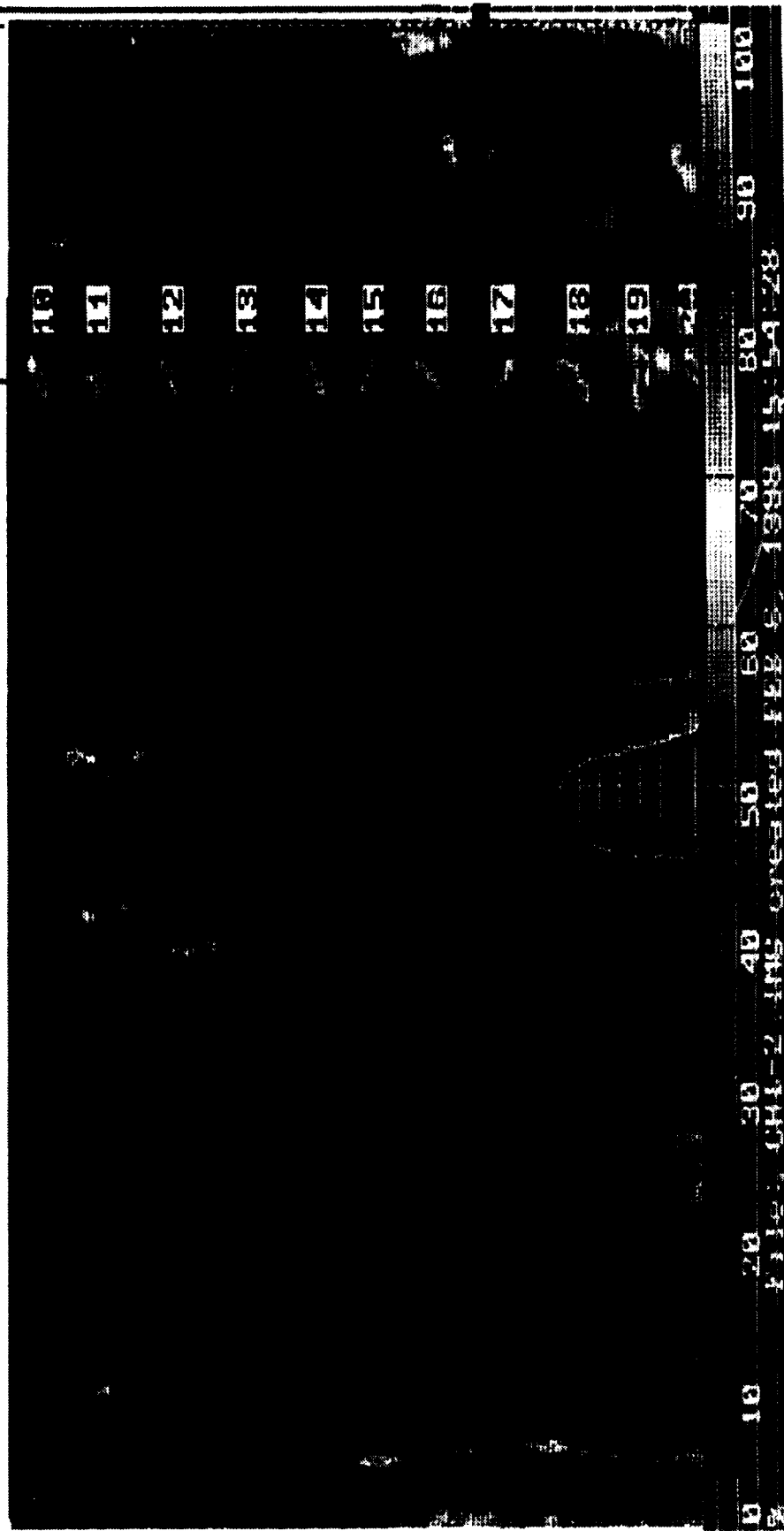


Figure A5.—Processing and test data for Port #7 of AMB-21 surge duct (page 15).



TEST REPORT

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FAA Repairstation Number OYCR172L

Page 1 of 2

COMPOSITES HORIZONS, INC. 1471 INDUSTRIAL PARK STREET COVINA, CA 91722-3499 ATTN: RANDY MAY	OCMTL NO.: 971787 DATE OF REPORT: 12-23-97 PURCHASE ORDER NO: 15902 PHONE: 818-33-10861 FAX: 818-339-3220
--	---

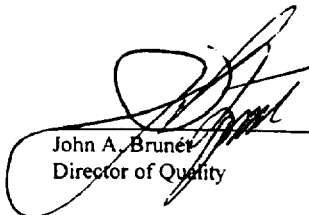
TYPE OF TEST:	RESIN CONTENT BY MATRIX DIGESTION
MATERIAL IDENTIFICATION:	GRAPHITE COMPOSITE MATERIAL
LOT/BATCH/SERIAL NO.:	BATCH # PRE 10761
SPECIFICATION/REVISION:	N/A
TEST PROCEDURE:	ASTM-D-792 / D-3171 / D-2734
SPECIMEN CONDITIONS:	AS RECEIVED
TEST TEMPERATURE:	73°F
DATE OF TEST:	12-22-97

TEST NO.	LOT NO.	SPECIFIC GRAVITY	% RESIN CONTENT	% VOID VOLUME	% FIBER VOLUME
1	10761	1.58	26.74	1.47	66.16
2	10761	1.58	28.74	1.25	63.89
3	10761	1.58	27.12	1.44	65.72
AVERAGE:		1.58	27.53	1.39	65.26

REPORTED DENSITIES

Resin Density: 1.27 g/cc = 0.46 lb/in^3
Fiber Density: 1.78 g/cc = $0.064 \text{ lb/in}^3 \rightarrow \text{T650-35, 8HS, 3K, with UC309 size}$

This is to certify that the above tests were performed in accordance with the terms of the purchase order requirements.
Test equipment is calibrated with standards traceable to the NIST


John A. Bruner
Director of Quality

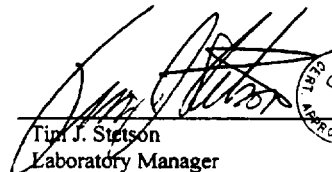

Tim J. Stetson
Laboratory Manager

Figure A5c.—Processing and quality control of Part #10 of S/N #003 for
AMB-21 Surge Duct (page 1).



TEST REPORT

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FAA Registration Number OYCR172L

Page 2 of 2

COMPOSITES HORIZONS, INC.
1471 INDUSTRIAL PARK STREET
COVINA, CA 91722-3499

ATTN: RANDY MAY

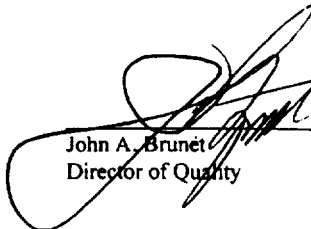
OCMTL NO.: 971787
DATE OF REPORT: 12-23-97
PURCHASE ORDER NO: 15902
PHONE: 818-33-10861
FAX: 818-339-3220

TYPE OF TEST: TG (BY TMA)
MATERIAL IDENTIFICATION: GRAPHITE COMPOSITE MATERIAL
LOT/BATCH/SERIAL NO.: BATCH # PRE 10761
SPECIFICATION/REVISION: ES0TF536 S1
TEST PROCEDURE: ASTM-D-3418
SPECIMEN CONDITIONS: POST CONDITIONED AT 250°F FOR 16 HOURS
TEST TEMPERATURE: 25°C - 350°C @ 10°C / MIN
DATE OF TEST: 12-23-97

TEST NO.	TG (°C)
BATCH # PRE 10761	281
BATCH # PRE 10761	288
BATCH # PRE 10761	287
AVERAGE:	285

EQUIPMENT	CONTROL NUMBER	CALIBRATION DATE	CALIBRATION DUE
BALANCE	1588	6-5-97	6-5-98
DSC	1695	11-5-97	-

This is to certify that the above tests were performed in accordance with the terms of the purchase order requirements.
Test equipment is calibrated with standards traceable to the NIST


John A. Brunet
Director of Quality



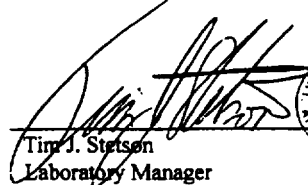

Tim J. Stetson
Laboratory Manager



Figure A5c.—Processing and quality control of Part #10 of S/N #003 for AMB-21 Surge Duct (page 2).

S/N 003

COMPOSITES HORIZONS, INC. COVINA, CALIFORNIA		MASTER TRAVELER	PART NAME: Allied Signal Surge Duct PART NUMBER: R-3559406-1	
SERIAL NUMBER:		PAGE 3 OF 5		
OP NO.	OPERATION DESCRIPTION	REQUIRED TOOLING	FA	BO
060	Bag for Imidization and cure as follows:		2 PV 12/2/7	
070	Wrap the part with one layer of high temperature teflon release film and tape in place with Kapton tape. Place one layer of 0.005" steel shim around the lay-up and tape in place with Kapton tape. The shims should be cut into strips along the length and between the ends where the taper begins and the "bumps". The shims should overlap a minimum of 0.1" and a maximum of 0.2". Wrap the lay-up with at least one layer of Kapton shrink tape and tape in place with Kapton tape.		2 PV 12/2/7	
080	Apply fiberglass breather material and bag with one layer of Kapton using high temperature brown sealant NPO154. (Note: Use at least 2 high temperature thermocouples and a high temperature vacuum port.)		2 PV 12/2/7	
090	Cure as follows: 1) Apply full vacuum and check for leaks. 2) Vent part to atmosphere. 3) Apply 3-5 inches of Hg vacuum. 4) Raise Temperature to 420F ± 10F at 1-3F/minute. 5) Hold at 420F ± 10F for 120 ± 5 minutes. 6) Apply full vacuum. 7) Apply 200 ± 10 PSI pressure 8) Heat part to 600F ± 10F at 1-3F/minute. 9) Hold at 600F ± 10F for 165 ± 5 minutes. 10) Cool to 100F at 1-10F/minute (Note: Release pressure and vent vacuum when part reaches 400F ± 10F)		2 PV 12/2/7	

Figure A5c.—Processing and quality control of Part #10 of S/N #003 for AMB-21 Surge Duct (page 3).

COMPOSITES HORIZONS, INC. COVINA, CALIFORNIA		MASTER TRAVELER	PART NAME: Allied Signal Surge Duct PART NUMBER: R-3559406-1	
SERIAL NUMBER:		PAGE 4 OF 5		
OP NO.	OPERATION DESCRIPTION	REQUIRED TOOLING	FA	BO
100	Verify, date and stamp cure chart.		CH 2	
110	Post Cure: (Note: The Post Cure should be performed within 24 hours after the completion of the initial cure and the part should be freestanding during the post cure process.) 1) Raise Temperature to 450F ± 10F in 70 minutes and hold for a minimum of 120 minutes. 2) Raise Temperature to 490F ± 10F in 30 minutes and hold for a minimum of 120 minutes. 3) Raise Temperature to 550F ± 10F in 30 minutes and hold for a minimum of 120 minutes. 4) Raise Temperature to 600F ± 10F in 60 minutes and hold for a minimum of 360 minutes. 5) Raise Temperature to 625F ± 10F in 45 minutes and hold for a minimum of 720 minutes. 6) Lower Temperature to 150F ± 10F in a minimum of 120 minutes		12/11/17 DAL 12/15/17	
120	Scribe EOP lines on the outside of the part per the Engineering drawing		MB 12-11	
130	Remove part from the tool and trim excess resin flash from the panel edges.		MB 12-11	
140	Trim part to trim lines. The excess material from the composite surge duct should be tagged for testing.		MB 12-12	
150	Assembly Bond Process: Sand the Titanium and Composite bond surfaces with 180-240 grit sandpaper until all the "shine" has been removed from the surfaces.		MB 12-15	
160	Remove the loose particles from the surfaces by blowing the surfaces with clean, dry shop air.		MB 12-15	

Figure A5c.—Processing and quality control of Part #10 of S/N #003 for AMB-21 Surge Duct (page 4).

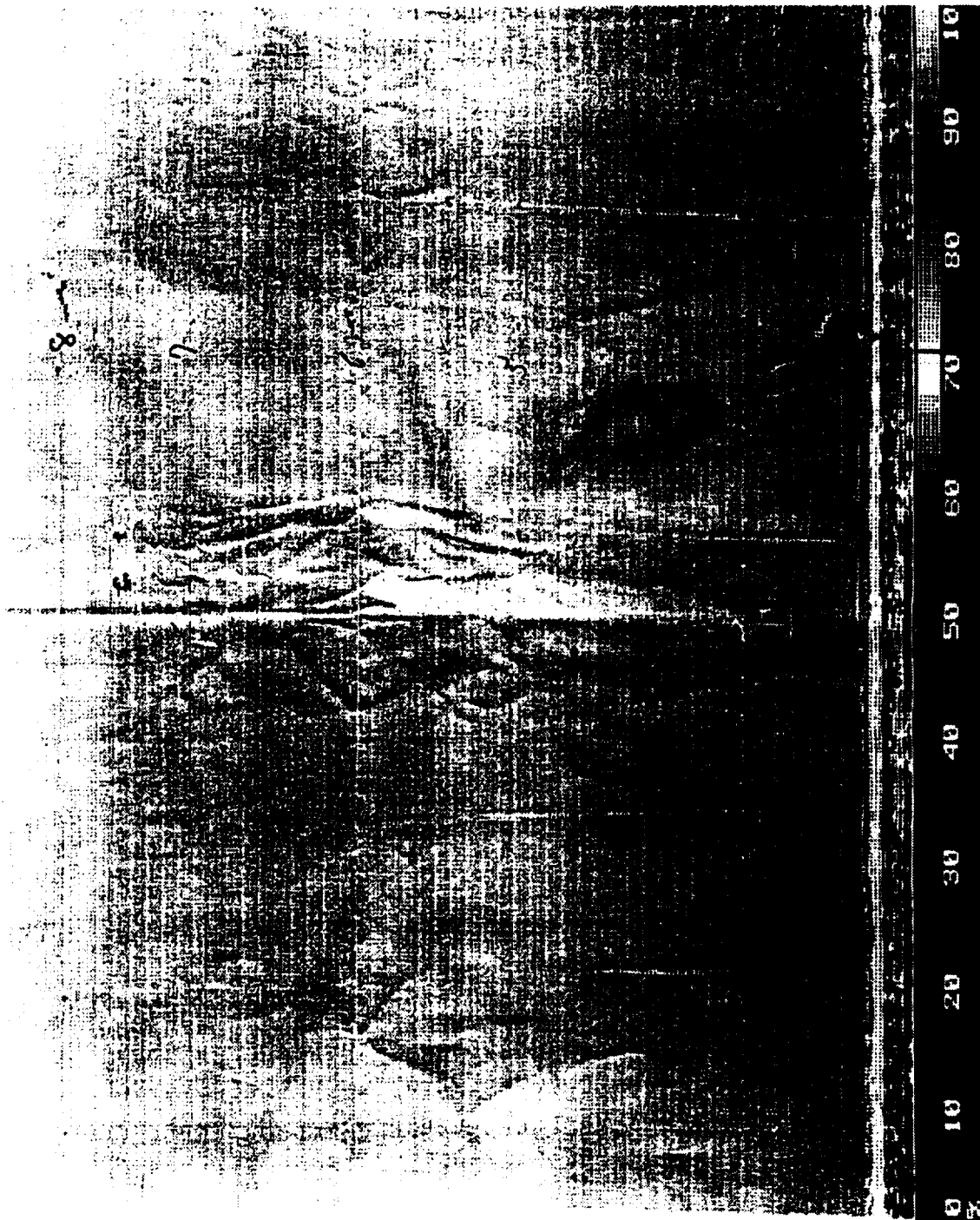


Figure A5c.—Processing and quality control of Part #10 of S/N #003 for AMB-21 Surge Duct (page 5).

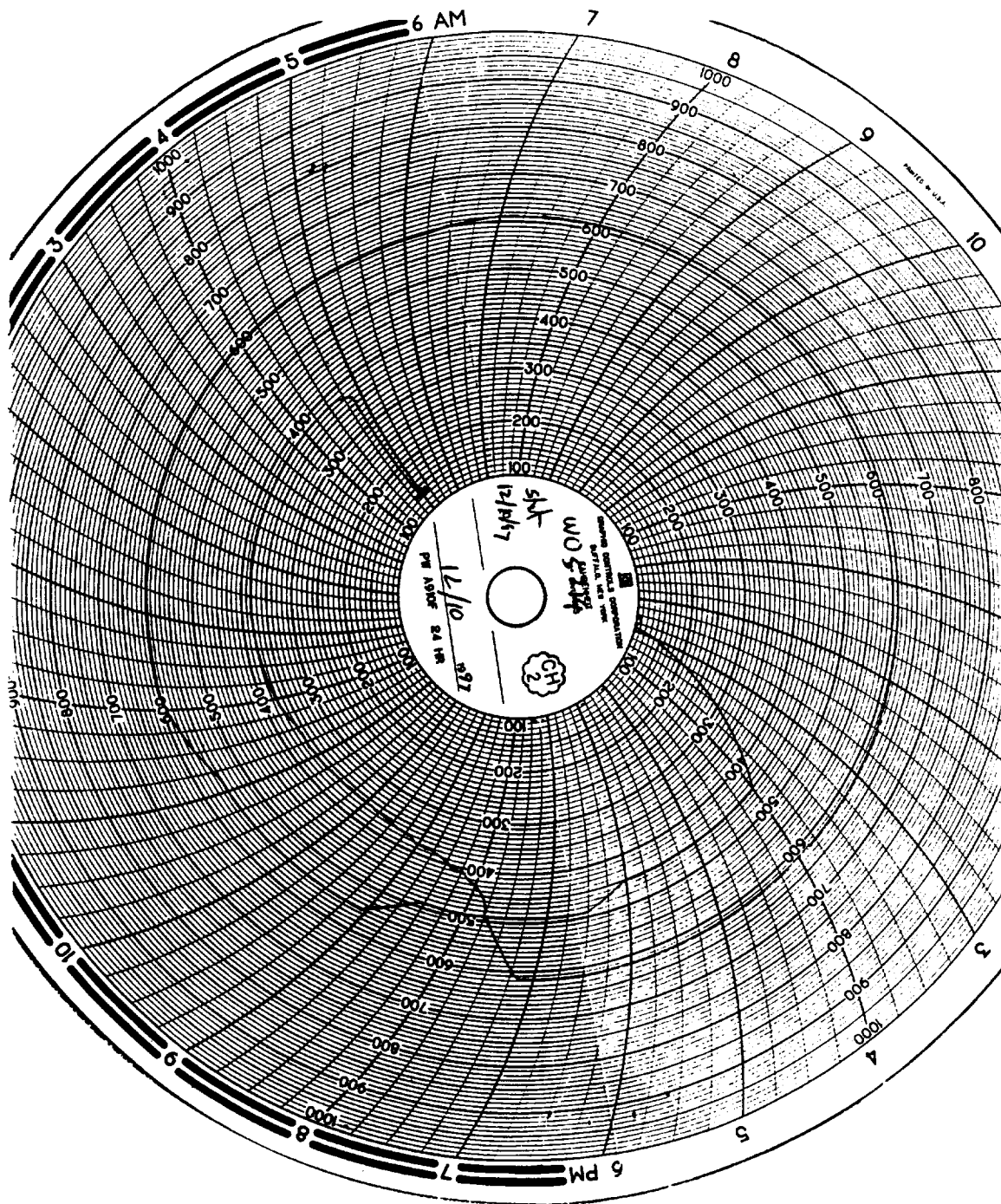


Figure A5c.—Processing and quality control of Part #10 of S/N #003 for AMB-21 Surge Duct (page 6).

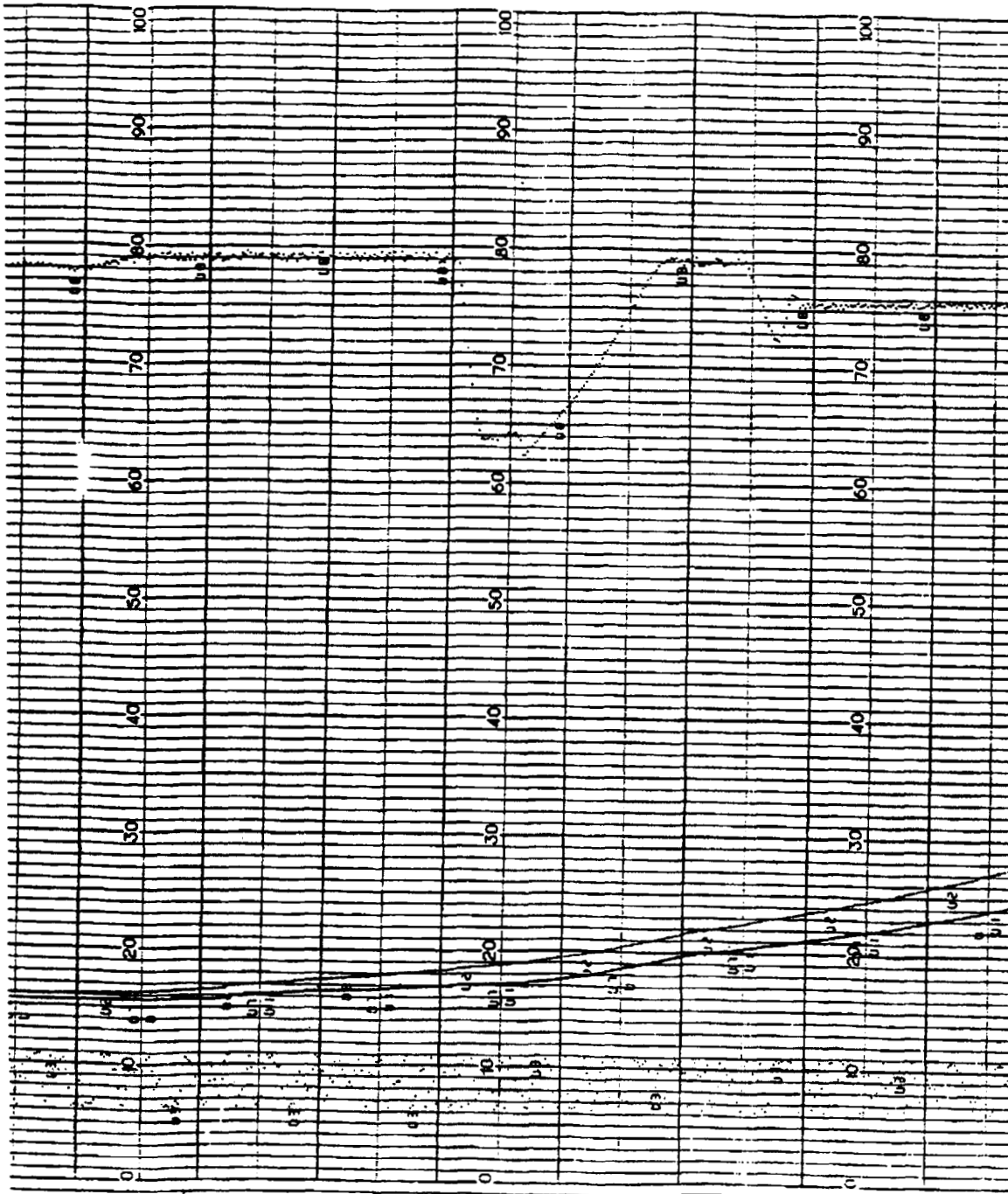
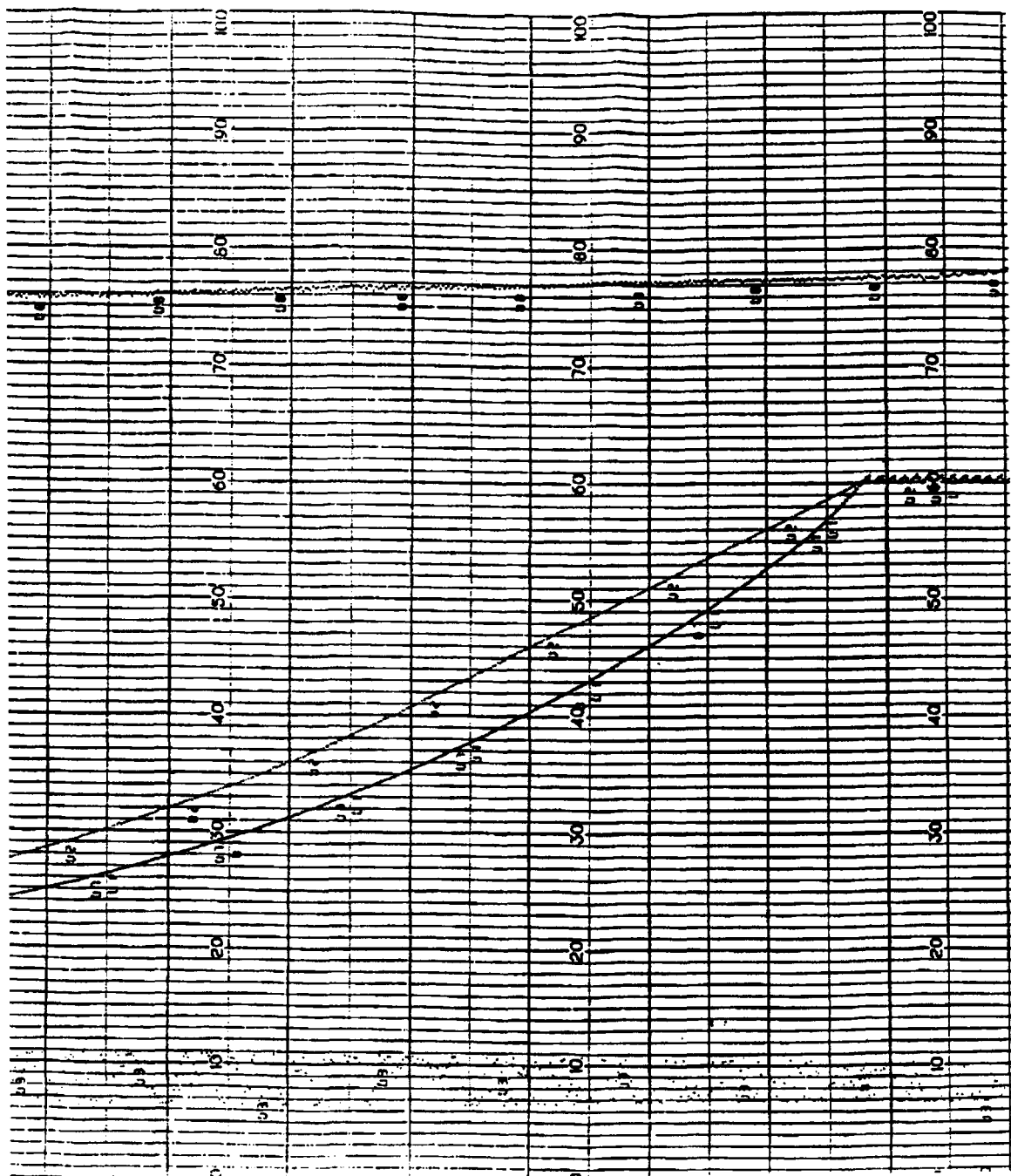


Figure A5c.—Processing and quality control of Part #10 of S/N #003 for AMB-21 Surge Duct (page 7a).



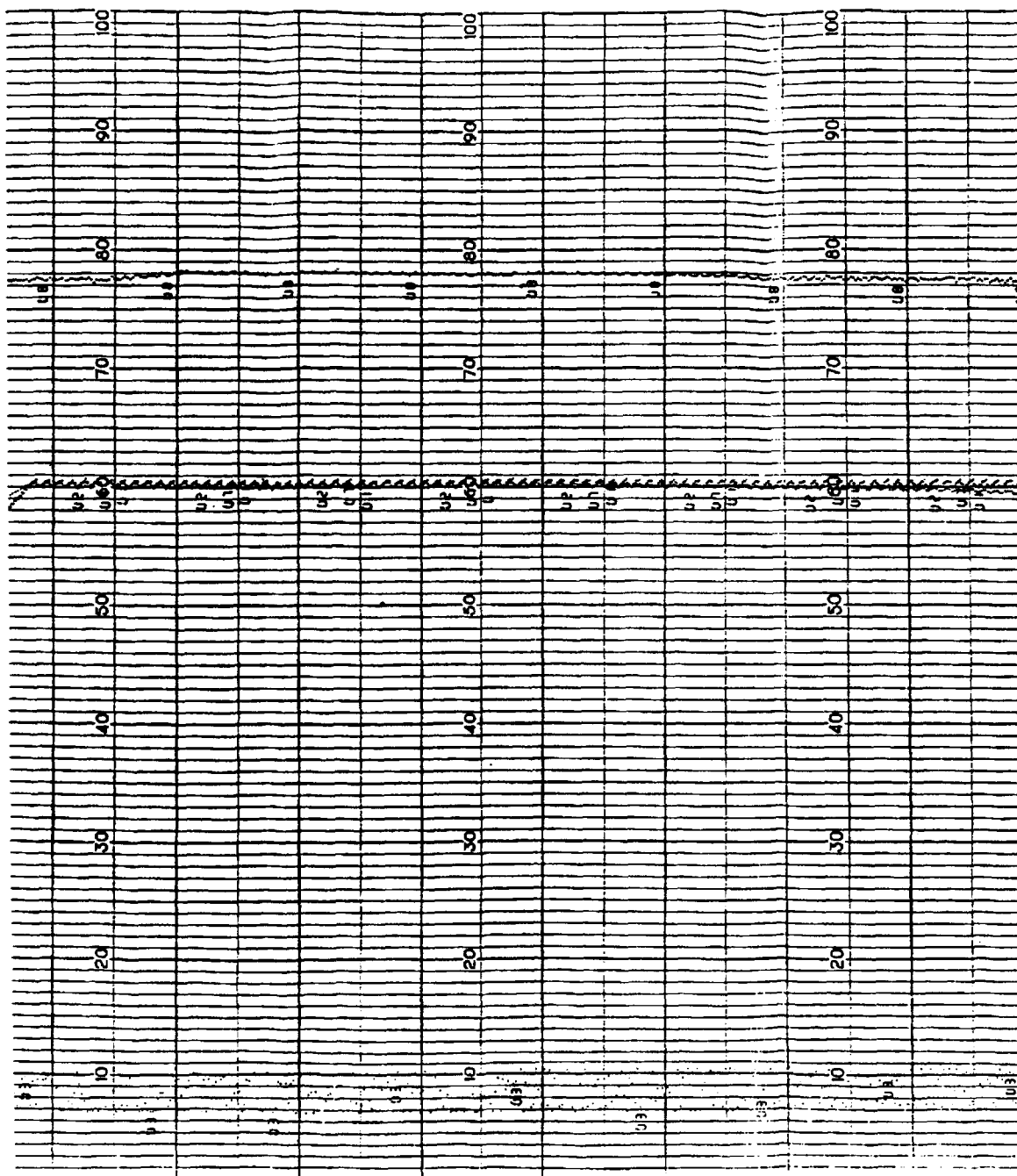


Figure A5c.—Processing and quality control of Part #10 of S/N #003 for AMB-21 Surge Duct (page 8a).

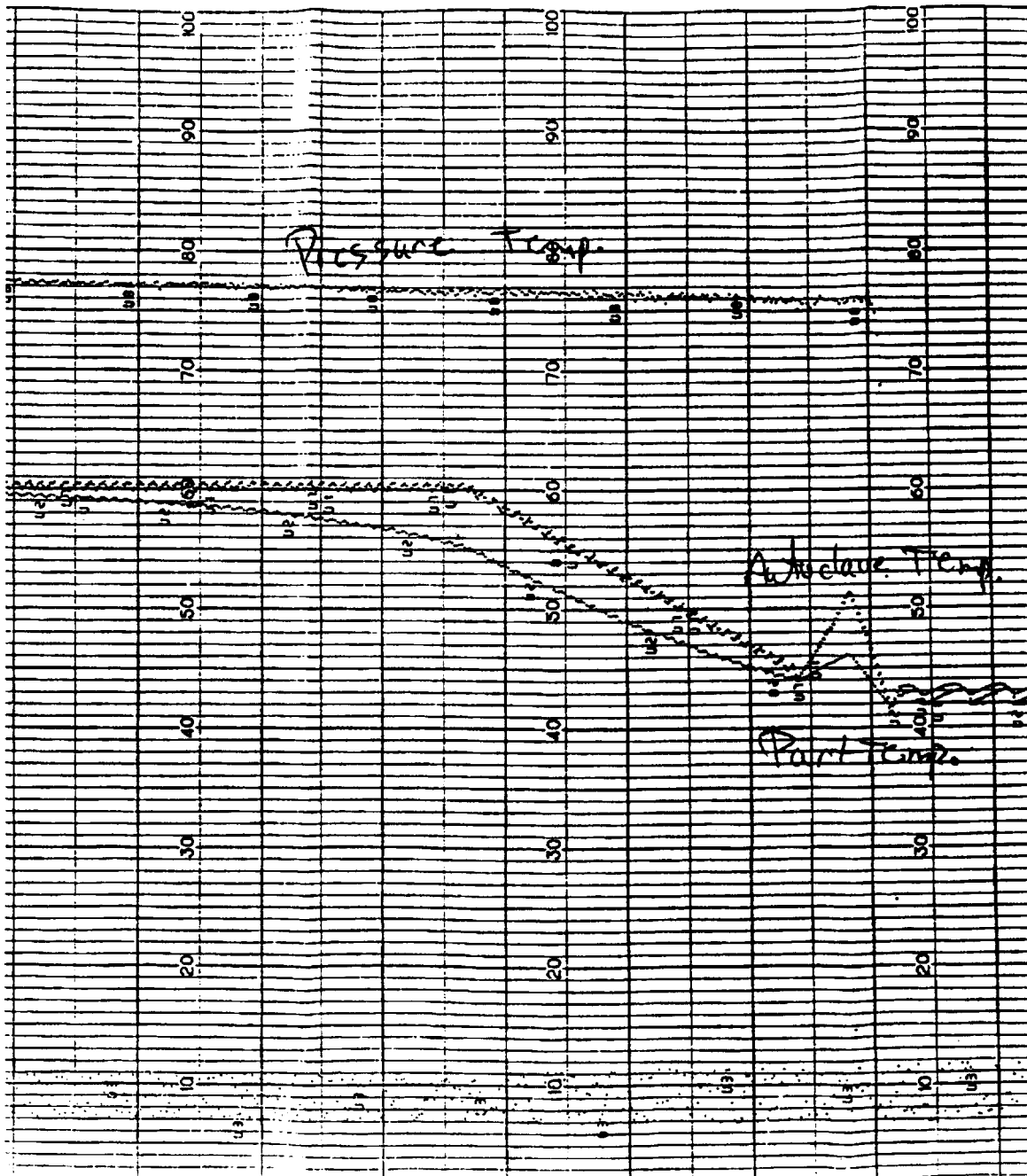


Figure A5c.—Processing and quality control of Part #10 of S/N #003 for AMB-21 Surge Duct (page 8b).

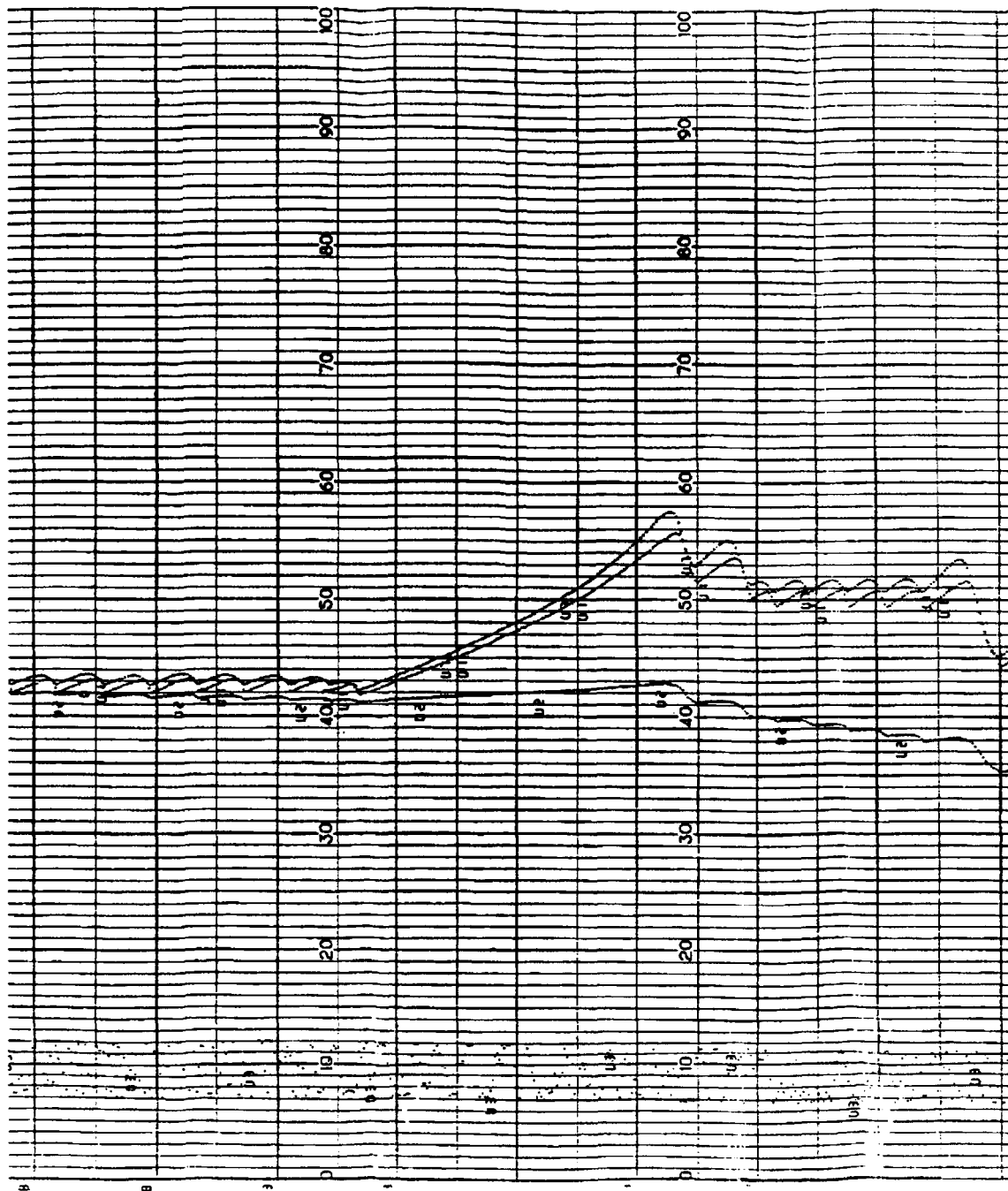


Figure A5c.—Processing and quality control of Part #10 of S/N #003 for AMB-21 Surge Duct (page 9a).

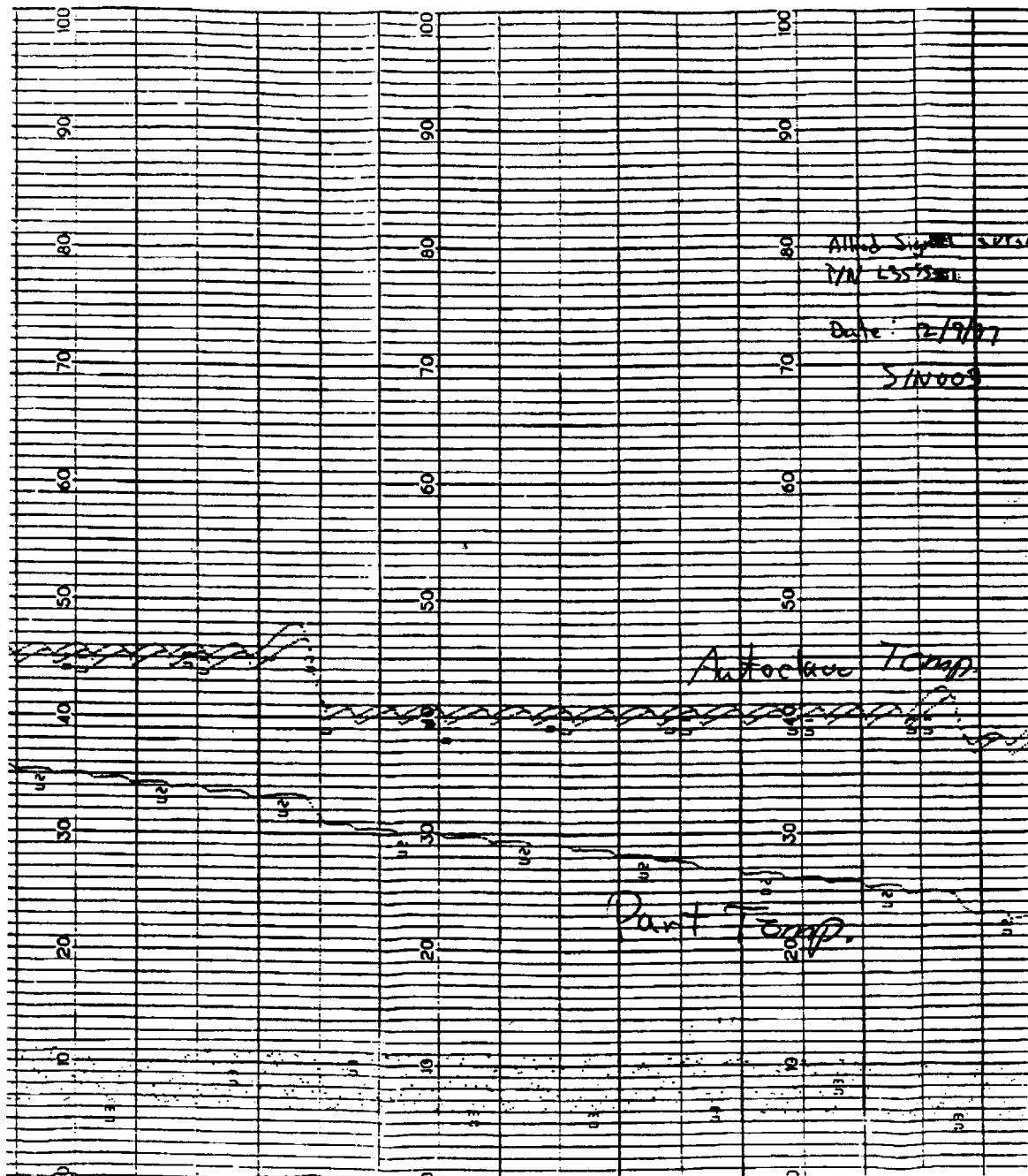


Figure A5c.—Processing and quality control of Part #10 of S/N #003 for AMB-21 Surge Duct (page 9b).



TEST REPORT

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FAA Registration Number OYCR172L

Page 1 of 2

COMPOSITES HORIZONS, INC.
1471 INDUSTRIAL PARK ST.
COVINA, CA. 91722-3499

ATTN: RANDY MAY

OCMTL NO.: 980888
DATE OF REPORT: 06-11-98
PURCHASE ORDER NO: 21527
PHONE: (626) 331-0861
FAX: (626) 331-3220

TYPE OF TEST: GLASS TRANSITION BY TMA
MATERIAL IDENTIFICATION: GRAPHITE COMPOSITE RING
LOT/BATCH/SERIAL NO.: P/N: R-355406-1; S-N: 003
SPECIFICATION/REVISION: G.E E 50TF36 S-1
TEST PROCEDURE: ASTM-E-831
SPECIMEN CONDITIONS: 8 HOURS @ 250°F
TEST TEMPERATURE: 25°C TO 350°C @ 10°C / MINUTE; LOAD: 2 GRAMS
DATE OF TEST: 06-10-98

LOT I.D. NUMBER	T _g °C
P/N: R-355406-1; S-N: 003	280
P/N: R-355406-1; S-N: 003	282
P/N: R-355406-1; S-N: 003	287

NOTE: For Information Only

EQUIPMENT:	CONTROL NUMBER:	CALIBRATION DATE:	CALIBRATION DUE DATE:
TMA	01922	06-05-98	07-05-98
WEIGHT SET	01466	03-03-98	03-03-99

This is to certify that the above tests were performed in accordance with the terms of the purchase order requirements.
Test equipment is calibrated with standards traceable to the NIST


John A. Brunet
Director of Quality



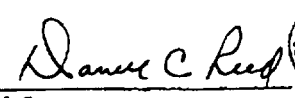

Tim J. Stetson
Laboratory Manager



Figure A5d.—Fabrication test data for AMB-21 Surge Duct (page 1).



TEST REPORT

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FAA Registration Number OYCR172L

Page 2 of 2

COMPOSITES HORIZONS, INC.
1471 INDUSTRIAL PARK ST.
COVINA, CA. 91722-3499

ATTN: RANDY MAY

OCMTL NO.: 980888
DATE OF REPORT: 06-11-98
PURCHASE ORDER NO: 21527
PHONE: (626) 331-0861
FAX: (626) 331-3220

TYPE OF TEST: RESIN CONTENT BY MATRIX DIGESTION
MATERIAL IDENTIFICATION: P/N: R-3559406-1; GRAPHITE COMPOSITE RING
LOT/BATCH/SERIAL NO.: S/N: 003
SPECIFICATION/REVISION: G.E E 50TF36 S-1
TEST PROCEDURE: ASTM-D-3171; PROCEDURE "A"
SPECIMEN CONDITIONS: AS RECEIVED
TEST TEMPERATURE: 75°C
DATE OF TEST: 06-08-98

TEST NO.	LOT #	SPECIFIC GRAVITY	% RESIN CONTENT	% VOID VOLUME	% FIBER VOLUME
1	003	1.57	29.44	1.90	63.86
2	003	1.56	30.35	1.98	63.08
3	003	1.58	29.83	1.30	63.46
AVERAGE:		1.57	29.94	1.73	63.43
STANDARD DEVIATION:		0.01	0.37	0.37	0.41
COEFFICIENT OF VARIATION:		0.64	1.33	21.32	6.54

REPORTED DENSITIES, gms/cc³

Resin Density 1.31

Fiber Density 1.76

EQUIPMENT ITEM:	CONTROL NUMBER:	CALIBRATION DATE:	CALIBRATION DUE DATE
Sartorius analytical Balance	01588	05-06-98	05-06-99
Blue M Oven	1607	07-30-97	07-30-98

This is to certify that the above tests were performed in accordance with the terms of the purchase order requirements.
Test equipment is calibrated with standards traceable to the NIST

John A. Brinét
Director of Quality

Tim J. Stetson
Laboratory Manager

Figure A5d.—Fabrication test data for AMB-21 Surge Duct (page 2).

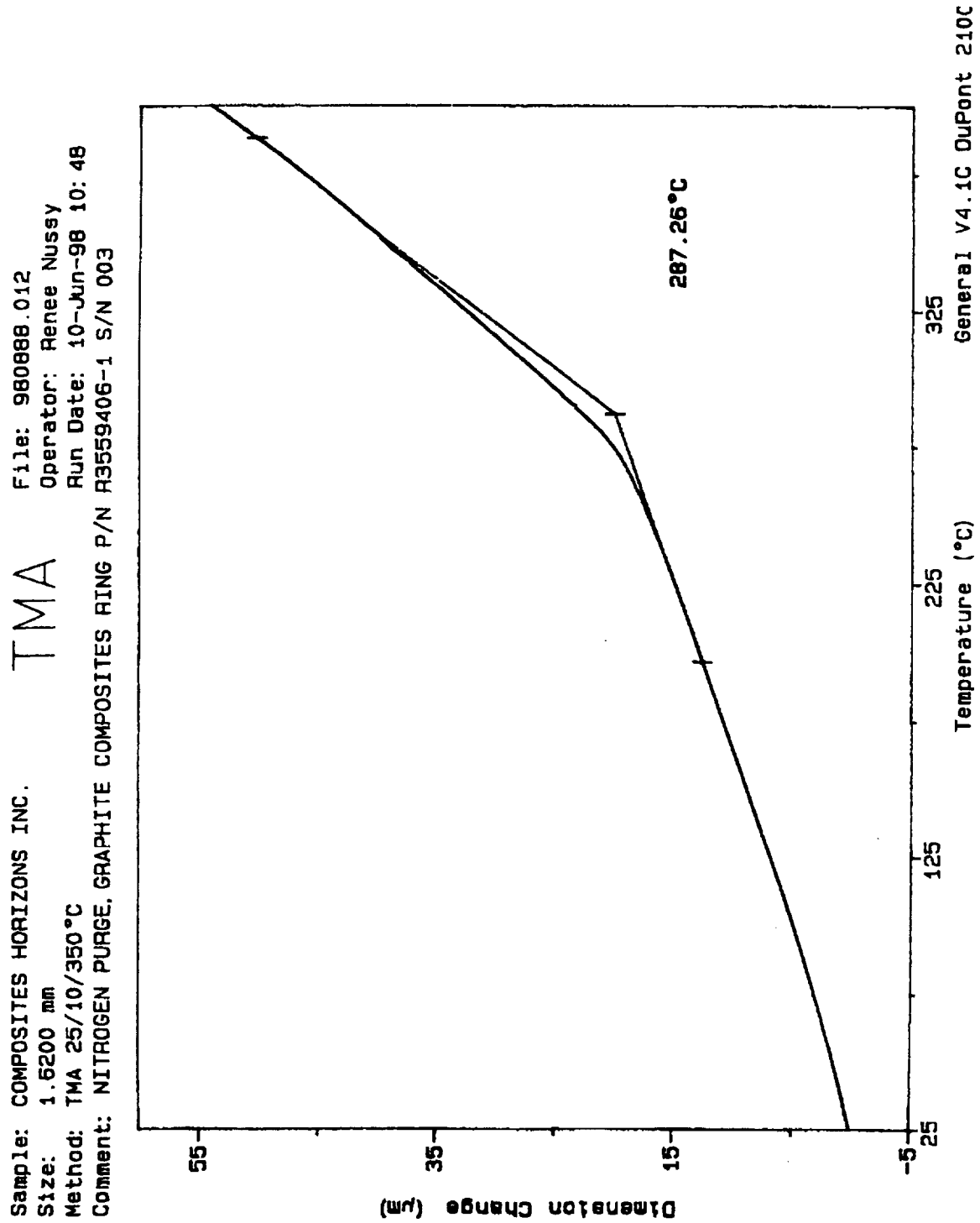


Figure A5d.—Fabrication test data for AMB-21 Surge Duct (page 3).

Sample: COMPOSITES HORIZONS INC.

Size: 1.7600 mm

Method: TMA 25/10/350 °C

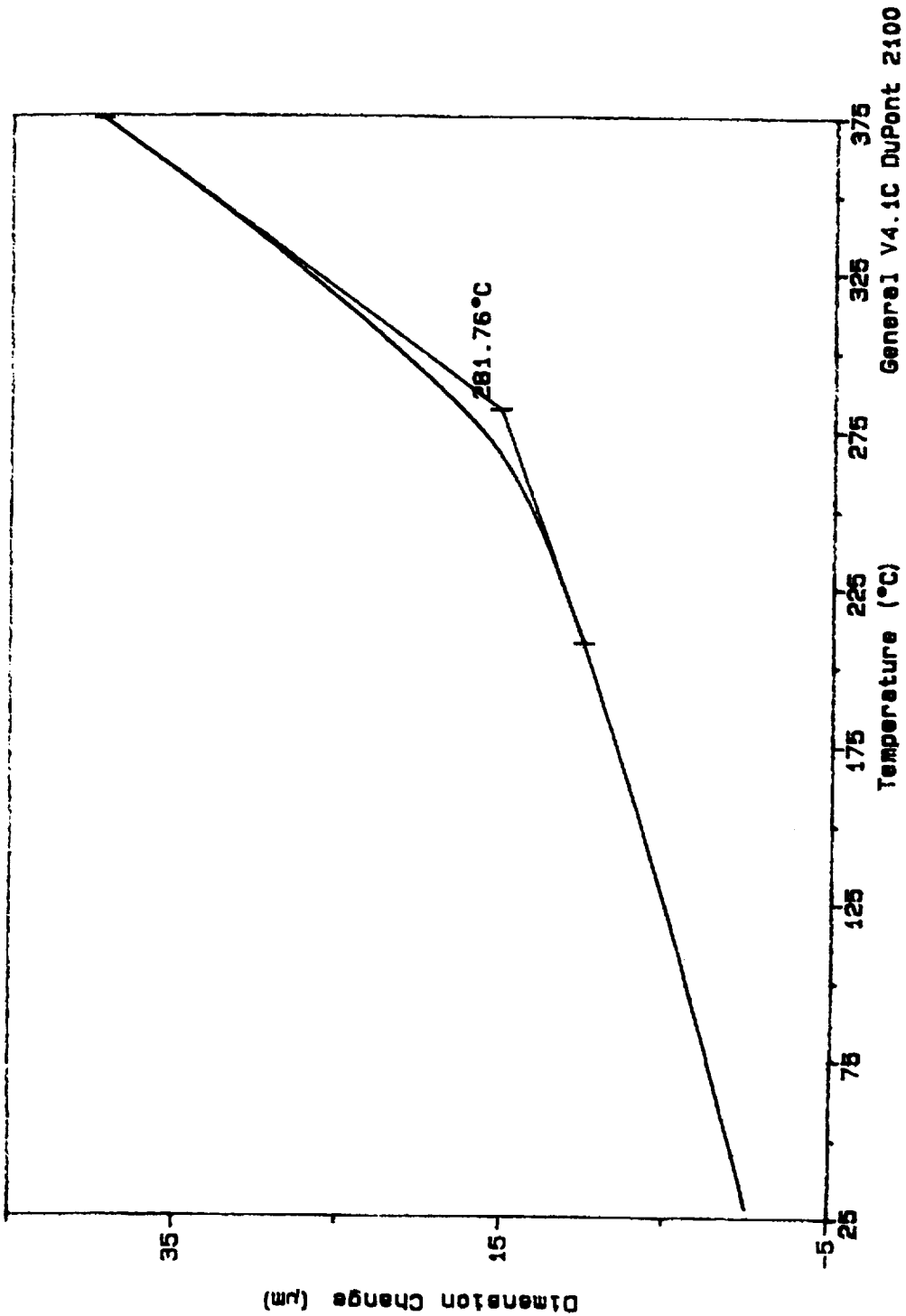
Comment: NITROGEN PURGE, GRAPHITE COMPOSITES RING P/N R3559406-1 S/N 003

TMA

File: 980888.005

Operator: Renee Nussy

Run Date: 10-Jun-98 08:47



General V4.1C DuPont 2100

Figure A5d.—Fabrication test data for AMB-21 Surge Duct (page 4).

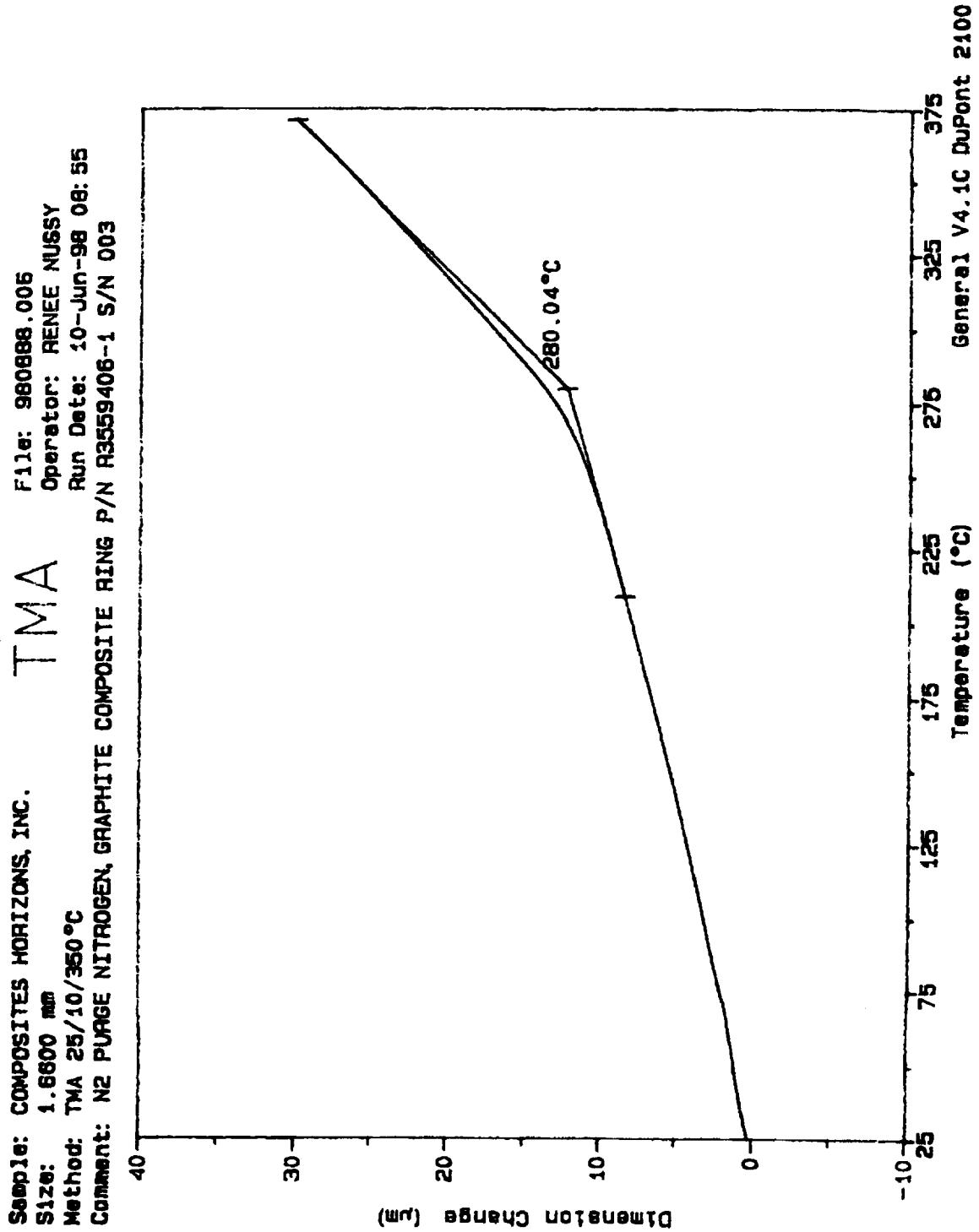


Figure A5d.—Fabrication test data for AMB-21 Surge Duct (page 5).

**SONIC TESTING & ENGINEERING INC**10727 S. Garfield Ave. • South Gate, Calif. 90280
(310) 862-8157 • (213) 771-6507 • Fax: (310) 862-4624

CERTIFICATION OF CONFORMANCE

SOLD TO COMPOSITES HORIZONS, INC. 1471 INDUSTRIAL PARK ST. COVINA CA 91722-3499		SHIP TO COMPOSITES HORIZONS, INC. 1471 INDUSTRIAL PARK ST. COVINA CA 91722-3499	
CUSTOMER P.O. NO. 21593		CUSTOMER SHIPPER NO. 09076	
MATERIAL		NET 30 DAYS	
COM002		DATE RECEIVED 06/22/1998	
DATE RECEIVED		DATE SHIPPED / /	
BUYER		Tom Hynes JR.	
ITEM	QUANTITY REMOVED	PART NUMBER/DESCRIPTION/PROCESS	QTY. ACCEPTED
01	1.000 Ea.	S5219 DUCT REQ.# 11593 *U.T. INSPECTION USING CONTACT THROUGH - TRANSMISSION TECHNIQUE REVEALS NO UNBONDS. S P E C I F I C A T I O N S ULTRASONIC INSPECT METAL TO COMPOSITE BOND AREA	ULTRASONIC ***** Ea.

Page # 1 of 1

WE HEREBY CERTIFY THE PARTS LISTED HAVE BEEN TESTED IN CONFORMANCE WITH THE SPECIFICATION NOTED. THIS REPORT REPRESENTS SONIC TESTING & ENGINEERING, INC. INTERPRETATION OF THE RESULTS OBTAINED FROM THE TEST AND IS NOT TO BE CONSTRUED AS A GUARANTY OR WARRANTY OF THE CONDITION OF THE MATERIALS TESTED. SONIC TESTING & ENGINEERING, INC. SHALL NOT BE HELD LIABLE FOR MISINTERPRETATION OF CONDITIONS. LOSS, DAMAGE, INJURY OR DEATH ARISING FROM OR ATTRIBUTABLE TO DELAY PRECEDING A TEST OR SUBSEQUENT TO PERFORMANCE OF A TEST.

PARTS WERE NOT SUBJECTED TO MERCURY CONTAMINATION

By _____
KELLY L. BROWN UT L-41 06/25/1998

By _____

By _____

Figure A5d.—Fabrication test data for AMB-21 Surge Duct (page 6).

COMPOSITES HORIZONS, INC. INSPECTION REPORT						
CUSTOMER: ALLIED SIGNAL		PART NAME: COMPOSITE SURGE DUCT ASSY.		PN: R3559408-1	S/N: 003	PAGE 1 OF 3 W.O.: 5219
DRAWING NO.: L3595551		REV.		ENGR	QA	DATE: 6/29/98
ITEM	ZONE	DIMENSION	MEASURED	ACCEPT	REJECT	COMMENTS
1	G8	4.954 - 4.984 1.0100A	4.977	CH QAG		
2	E8	5.631 - 5.651 0.0200A/B/C	5.641	CH QAG		
3	D7	Ø.128 - .132 (3X)	.132	CH QAG		EQUALLY SPACED THRU (FIND 3) ONLY RIVET MAY BE INSTALLED BY A.S. E.
4	D7	Ø.128 - .132	.132	CH QAG		
5	D7	Ø.128 - .132	.132	CH QAG		
6	F2	1.070 - 2.030	2.001	CH QAG		
7	F2	R1.520 - 1.580	1.551	CH QAG		
8	F2	R.130 - .150 (2X)	.140	CH QAG		
9	F2	R.130 - .150	.140	CH QAG		
10	E2	.777 - .817	.800	CH QAG		
11	E2	.596 - .636	.615	CH QAG		
12	E2	R.070 - .090 (3X)	.080	CH QAG		
13	E2	R.070 - .090	.080	CH QAG		
14	E2	R.070 - .090	.080	CH QAG		
15	D2	R.100 - .120	.110	CH QAG		
16	D2	109.50 - 110.50°	110.00°	CH QAG		
17	D2	R.2320 - .2350	—			CANNOT INSPECT

Figure A5d.—Fabrication test data for AMB-21 Surge Duct (page 7).



COMPOSITES HORIZONS, INC. INSPECTION REPORT						
CUSTOMER: ALLIED SIGNAL		PART NAME: COMPOSITE SURGE DUCT ASSY.		P/N: R3589406-1		S/N: 003
DRAWING NO.: L3695551		REV.		ENGR		W.O.: 8218
						DATE: 6/29/98
ITEM	ZONE	DIMENSION	MEASURED	ACCEPT	REJECT	COMMENTS
18	D1	.085 - .095	1087	CH Q49		
19	D1	.025 - .035	1033	CH Q49		
20	C2		Accept	CH Q49		
21	B5	MATERIAL TITANIUM	Accept	CH Q49		(NOTE 5)
22	H7	R.095 - .155	1125	CH Q49		
23	H7	R.220 - .280 (4X)	1250	CH Q49		
24	H7	R.220 - .280	1250	CH Q49		
25	H7	R.220 - .280	.250	CH Q49		
26	H7	R.220 - .280	1250	CH Q49		
27	G6	R.095 - .155	1125	CH Q49		
28	G6	.325 - .425	1408	CH Q49		
29	G6	2.050 - 2.150	2.055	CH Q49		
30	F8	22.400 - 22.500	22.423	CH Q49		
31	F6		Accept	CH Q49		TOOL SIDE
32	F6	(99193-R3589406-X)	Accept	CH Q49		(NOTE 2)
33	B5	PLY TABLE	Accept	CH Q49		(SEE NOTE 4)
34	B5	MATERIAL: RESIN POLYIMIDE	Accept	CH Q49		(NOTE 4)

Figure A5d.—Fabrication test data for AMB-21 Surge Duct (page 8).

COMPOSITES HORIZONS, INC. INSPECTION REPORT						
CUSTOMER: ALLIED SIGNAL		PART NAME: COMPOSITE SURGE DUCT ASSY.		P/N: R3580406-1	S/N: 003	W.O.: 5219
DRAWING NO.: L3505551		REV.	ENGR	QA	DATE: 6/29/98	
ITEM	ZONE	DIMENSION	MEASURED	ACCEPT	REJECT	COMMENTS
35	B5	PRIOR TO BONDING	Accept	CH Q49		(NOTE 6)
36	C5	BONDING	Accept	CH Q49		(NOTE 7)
37						
38						
39						
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50						
51						

IR5219.001

Figure A5d.—Fabrication test data for AMB-21 Surge Duct (page 9).

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13. ABSTRACT (Maximum 200 words) This document, submitted by AlliedSignal Engines (AE), a division of AlliedSignal Aerospace Company, presents the program final report for the <u>Advanced High Temperature Polymer Matrix Composites for Gas Turbine Engines Program Expansion</u> in compliance with data requirements in the statement of work, Contract No. NAS3-97003. This document includes: 1-Technical Summary: a) Component Design, b) Manufacturing Process Selection, c) Vendor Selection, and d) Testing Validation; 2-Program Conclusion and Perspective. Also, see the Appendix at the back of this report. This report covers the program accomplishments from December 1, 1996, to August 24, 1998. The <u>Advanced High Temperature PMC's for Gas Turbine Engines Program Expansion</u> was a one year long, five task technical effort aimed at designing, fabricating and testing a turbine engine component using NASA's high temperature resin system AMB-21. The fiber material chosen was graphite T650-35, 3K, 8HS with UC-309 sizing. The first four tasks included component design and manufacturing process selection, vendor selection, component fabrication and validation testing. The final task involved monthly financial and technical reports.				
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